WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

Reference No. 50-48

Report on a Survey of The Hydrography of Great South Bay made during the summer of 1950 for the Town of Islip, N. Y.

January 1951

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

January 22, 1951

Mr. Charles H. Duryea, Supervisor
Town of Islip
New York

Dear Sir:

I take pleasure in submitting herewith a Report on a Survey of the Hydrography of Great South Bay made during the summer of 1950 for the Town of Islip. You are, of course, well aware of the circumstances relative to the oyster industry which have led to this investigation. It may be appropriate in this place to explain why the Woods Hole Oceanographic Institution has been interested in cooperating in this study.

The Woods Hole Oceanographic Institution is a privately endowed, non-profit corporation engaged in the scientific study of the sea in all its aspects. The greater part of the Institution's work is carried out on the high seas and includes the study of currents and waves, the chemistry of ocean water, the life of the sea, the geology of the ocean basins, and the influence of the ocean on the weather. Much of this work is now being done in the interests of the United States Navy and other Governmental agencies. In the New York area the Woods Hole Oceanographic Institution has recently completed studies of the circulation of Raritan Bay in connection with the location of the outfall of a proposed trunk sewer to serve the Raritan River Valley. It has been engaged for some years in examining the problems arising from the disposal of waste materials at sea off New York Harbor. It is also conducting investigations of the shellfisheries for the Commonwealth of Massachusetts.

At the present time, we are very much interested in the conditions pertaining to the tidal bays and estuaries along the coast and are attempting to learn more of the ways in which these conditions affect the use and enjoyment of such waters by coastal communities. When conditions change from unknown causes or when changes threaten to occur as the result of proposed engineering works, it is most desirable to have an unbiased scientific estimate of the situation in order that the responsible public officials may be able to arrive at correct decisions. Our desire is to increase the background of scientific fact on which such estimates and decisions must rest. This can be done only by the careful study of such situations as now exist in Great South Bay.

Mr. Charles H. Duryea January 22, 1951

In submitting the present report, I should point out that a number of questions have been revealed which were not anticipated when the field work was in progress. These questions require special study before the investigation can be considered to be complete. The present report is consequently provisional in that it summarizes the progress to date and indicates questions which appear to warrant further examination.

Respectfully submitted,

Alfred C. Redfield

Alfred C. Redfield
Associate Director
Woods Hole Oceanographic Institution

ACR/jmb

Woods Hole, Mass.

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61 pages

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APPROVED FOR DISTRIBUTION ____________

Director

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I. ABSTRACT

Between July 25 and August 7, 1950, the Woods Hole Oceanographic Institution conducted a survey of Great South Bay. The purpose of this study was to attempt to determine the cause of the almost complete cessation of the once prosperous oyster industry. Statistics show that the seed oyster production of the bay declined steadily for ten years prior to 1935 and has subsequently been negligible. The yield of market oysters fell from a maximum of 350,000 bushels in 1929 to 60,000 in 1944 and is now non-existent.

Systematic records kept by the oyster companies, notably Bluepoints and Van der Borgh and Sons, provide strong evidence that the failure of oysters to fatten and grow properly is associated with the periodic occurrence in the bay of luxuriant "blooms" of microscopic plants which they have named "small forms" because of their minute size and difficulty of identification. This view is supported by experiments conducted by V. L. Loosanoff and J. B. Engle of the U. S. Fish and Wildlife Service who report that oysters stop feeding in the presence of heavy concentrations of algae.

The problem which the investigators were asked to examine was whether evidence could be found that the circulation of water in Great South Bay has altered in such a way as to account for the failure of the oyster industry or whether abnormal chemical conditions arising from pollution or otherwise might provide an alternate or supplementary explanation of the difficulty. The frequent changes in the inlets cutting the beach and particularly the apparent restriction of Fire Island Inlet and the new opening of Moriches Inlet in 1931 suggest that changes in the circulation of water have taken place and have led to various proposals for modifying or supplementing these openings. On the other hand, the duck farms along the tributaries of Bellport and Moriches Bays have increased production substantially during the past twenty years and it has been suspected that pollution resulting from these farms may have provided conditions favorable to the growth of the small form and have thus been responsible for the failure of plantings of market oysters.

An examination of records kept by the Coast and Geodetic Survey indicate that the tidal circulation of the bay has been reduced over the years. The change occurred prior to 1930 and thus preceded the decline in oyster production. The results of a survey of the salinity and tidal movement

made in 1907-08 for the New York City Water Supply Board, when compared with information obtained last summer, indicate that the change in conditions has been small except in the eastern extremity of the bay. There a most important alteration has taken place. Whereas in 1908 Bellport Bay was relatively fresh, having only 1/3 the salinity of sea water, it now contains about twice as much salt as formerly. This change undoubtedly results from the opening of Moriches Inlet which permits salt water to flow with the rising tide into Bellport Bay from Moriches Bay and Inlet.

The opinion is widely held that relatively brackish water is favorable to the production of seed oysters. It is believed, consequently, that the opening of Moriches Inlet may be responsible for the failure of the seed oyster industry which was formerly centered in Bellport Bay. However, in the greater part of Great South Bay, where formerly market oysters were planted, the change in circulation does not appear to be sufficient to account for the failure of oysters to fatten properly.

The results of the chemical studies indicate that the bay water is unusually rich in the products of decomposing organic matter. These materials appear to originate in the tributaries of Moriches Bay and the Carmans River from where they are carried westward across Great South Bay and provide nutriment for the growth of the great population of microscopic plants. These observations point strongly to the duck farms as the source of abnormal conditions in the bay.

The survey has thus revealed two conditions which in combination appear to be responsible for the unfavorable conditions affecting the oyster industry. One is the pollution of the bay by wastes from the duck farms which provides nourishment for the great population of microscopic plants which appear each summer; the other is the local change in circulation occasioned by the opening of Moriches Inlet which has increased the salinity of Bellport Bay. In considering remedial measures both these conditions should be taken into account.

Since the state of pollution depends on the balance between the rate at which pollutants are added and their removal by the circulation of water, the conditions might be improved by enlarging the inlets or cutting new openings designed to increase the flushing of the bay. To be effective these engineering works would be prohibitively expensive and their effectiveness and permanence would be uncertain. In addition, they would not restore the low salinity of the eastern end of Great South Bay which appears to favor seed oyster production.

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A second alternative is to reduce the pollution at its source by preventing the wastes from the duck farms from reaching the water. The manure might become a valuable by-product of the farms if procedures were developed for using it for fertilizer. Even if such procedures did not yield a profit, they might at least pay the costs of preventing pollution. While this expedient might be expected to improve the conditions in the bay as a whole and thus might lead to a restoration of market oyster production, it would not restore the low salinity of Bellport Bay, on which the seed oyster production supposedly depended, unless Moriches Inlet were to be permanently closed. If this were done, the conditions in Great South Bay might be expected to be restored to very nearly those obtaining prior to 1930.

A third alternative, which has much to commend it, is to prevent the exchange of water between Great South Bay and Moriches Bay. If this were accomplished the wastes from most of the duck farms would be prevented from reaching Great South Bay. In addition, the waters of Bellport Bay might be expected to become much fresher and the conditions would favor the restoration of seed oyster production in that area. Inasmuch as it is now proposed to bridge the narrows at Smith Point to provide a roadway to Great South Beach, it is suggested that at reasonable additional expense the opening might be filled completely except for a lock for the passage of boats along the intercoastal waterway. Such construction would eliminate, or place under control, the movement of water between the bays and should lead toward a restoration of the conditions required for the production of both market and seed oysters. While this method of improving the conditions appears to be the most practical one, it should be realized that it would require either the maintenance of Moriches Inlet as an effective opening or the correction of the pollution of Moriches Bay, since otherwise the isolation of Moriches Bay from the ocean would lead to intolerable conditions.

II. INTRODUCTION

During the past twenty years, there has been a continuous decline in the productivity of the shellfish industry of Great South Bay, occasioned by the failure of seed oysters to set and of oysters planted for "marketing" to develop properly. The present study was undertaken at the initiation of the Long Island Fishermen's Association with the object of determining whether any conditions or changes in condition of the waters of the bay could be demonstrated which might account for the failure of the oysters to reproduce, grow and "fatten" properly. It was the hope that if the cause of the present conditions could be found, remedial measures would be indicated.

Two obvious possibilities have been suggested as the source of the changed conditions in Great South Bay. One is the effect of changes in the openings in the beach on the circulation of water in the bay; the other is pollution due to the duck farms which have become established along tributaries to the bay. Other possible changes resulting from human activities along the shores should also be considered.

The inlets show a history of continuous change. Fire Island Inlet is said to have been opened in 1690 (4). In 1851 Fire Island Light stood 0.6 miles from the western tip of Great South Beach. Since that time, the point has grown westward steadily for a distance of three and one-half miles until 1941 when its growth was arrested by the construction of the breakwater. The result has been the lengthening and narrowing of the channel, as shown in Figure 1. The flow through Fire Island Inlet, measured in 1907 by Whipple (10) was 1900 million cubic feet per tide. This is equal to about one-ninth the low tide volume of the bay.

An opening opposite Bellport is shown in charts printed in 1797 and in 1829. It was closed about 1834 (4). The sea breached this point during the hurricane of 1938 but the opening did not persist.

Moriches Inlet was open in 1797 but was closed by 1829. It was opened by a storm on March 1, 1931 and has since remained open though its persistence is in doubt. Estimates made in 1939 indicated a flow of 1,000 million cubic feet per tide which has become reduced to 40 - 60 million cubic feet per tide in 1950 (6).

An opening into Shinnecock Bay existed prior to 1888. The present Shinnecock Inlet was opened on September 21, 1938. Measurements the following year indicated a flow of

400 - 500 million cubic feet per tide.

Openings have also cut across Oak Island Beach for short periods from time to time.

These changes indicate that in recent years the access of the sea to Great South Bay is being reduced while the new openings into the eastern bays, which originally drained into Great South Bay, now have direct access to the sea. Fortunately, an extensive survey of the hydrography of Great South Bay was made in 1907-08 by Whipple (10). The report on this survey supplies an excellent reference from which to judge changes in present day conditions.

Changes in the population living along the shores of the bay and in the use to which the land is put should also be examined for their possible effect on the state of the bay's water. The population of the Towns of Babylon, Islip and Brookhaven has increased as follows (6):

1910	-	44,113
1920	-	53,871
1930	-	80,776
1940	-	107,596
1950	-	159,130

The present summer population is estimated at 272,000.

The region has not become heavily industrialized and no evidence of substantial industrial pollution has been reported to us. Limited areas near the principal coastal towns are closed to shellfishing because of domestic pollution, but in general such pollution is not extensive. The character of the agricultural use of the land has not changed greatly and there does not appear to be any deflection of ground water from the watershed into other regions.

The only unusual situation along the shore, which may be involved in the pollution of the bay are the duck farms. The numbers of ducks raised each year have increased substantially during the past twenty years. The farms are situated on Carmans River and the tributaries of Moriches Bay and it is evident that the waters of these streams are heavily contaminated by the excrement of the ducks.

In the bay itself the most impressive evidence of change is given by the statistics of the oyster industry supplied by the Conservation Department of the State of New York. Figure 2 shows that the value of the

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seed oysters produced in the bay declined steadily for ten years prior to 1935 and has subsequently been negligible. The yield of market oysters, shown in Figure 3, fell from a maximum of 350,000 bushels in 1929 to 60,000 in 1944 and is now non-existent. In the culture of market oysters, stock is usually imported from Long Island Sound and placed in Great South Bay to mature. The failure of the crop of market oysters is due to the failure of the oysters to grow and "fatten" properly after they are placed in the beds.

Other changes in the fauna and flora of the bay appear to be related to the circumstances affecting the oyster industry. Thus, the hard-shelled clam, Venus mercenaria, is no longer taken in its former abundance and good condition. Conversely, other organisms appear to thrive under the present environment, notably the tube worm, Hydroides hexagonus, which forms an unusually heavy incrustation on oysters shells and other submerged objects.

The most noticeable abnormality, however, is the exceptionally heavy growth of microscopic plant cells, which develop each summer. This organism is locally known as the "small forms" and is a green algae resembling a Chlorella. These are single cells 2 to 4 microns in size which sometimes occur in numbers of 3 million per cubic centimeter (2). They give the water an unusual yellowish color and cause such turbidity that a white disc 6 inches across cannot be seen at a depth of two feet. According to records supplied by Mr. Joseph B. Glancy of the Bluepoints Company, this growth usually appears in June. In some years the small forms disappear by the end of September; in others they may persist through December.

The study undertaken by the Woods Hole Oceanographic Institution during the summer of 1950 was directed primarily at determining the conditions of circulation in Great South Bay. The distribution of salinity was examined thoroughly as a basis for comparison with Whipple's data obtained in 1907-08. Measurements of the tidal exchange through Fire Island Inlet and in the narrows off Smith Point were made. The tidal currents in various parts of the bay were measured. Accessory chemical observations were taken in the course of this work including measurements of oxygen, phosphate, nitrate, ammonia, and pH; measurements which are of value as indicators of pollution.

The field party from the Woods Hole Oceanographic Institution was led by Dr. John C. Ayers who was assisted by Mr. Dean F. Bumpus and Mr. Nathaniel Corwin, hydrographers, and Dr. Francis A. Richards, Mr. George Crompton III and Miss Jean Keen, chemists. Their work was greatly facilitated by

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additional observers made available by the New York State Department of Conservation, the Superintendent of Highways of Suffolk County, the Bluepoints Company, and G. Van der Borgh and Son. Mr. Harry T. Tuthill and Mr. Samuel B. Cross of the Department of Highways, Mr. Alfred Tucker of the State Conservation Department, Mr. Joseph B. Glancy of the Bluepoints Company and the Messrs. Van der Borgh have been indispensable in supplying various recorded information bearing on the problem of Great South Bay. We also wish to acknowledge the assistance by the U. S. Coast and Geodetic Survey through their provision of a complete series of hydrographic charts of the region covering the period from 1844 to the present and the aid of Mrs. Maxwell Small of Bellport for providing historical information.

III. THE HYDROGRAPHY OF GREAT SOUTH BAY

Great South Bay is typical of the many embayments formed behind barrier beaches along the Atlantic coast south of Cape Cod. The bay is about 25 miles in length and varies in width from 1.5 to 5 miles. Its area is 90 square miles and its average depth at low water is 4.25 feet. The deeper parts of the bay do not exceed 13 feet in depth except in the narrower channels near the inlet, where depths up to 25 feet occur. Because of the restricted range of tide, a relatively small area bares at low water.

Figure 4 is a chart of the bay on which the place names used in this report are shown.

Fire Island Inlet is the only direct connection between Great South Bay and the ocean. To the west, the bay connects with the Atlantic through shallow channels leading into South Oyster Bay and thence through Jones Inlet. To the east, a narrow but relatively deep channel leads past Smith Point through Narrow Bay to Moriches Bay where further access to the sea is had through Moriches Inlet, and less directly through Shinnecock Inlet and Canal.

Tidal Circulation. The circulation of water in the bay is occasioned primarily by tidal currents. Because of the bay's extent and restricted depth, the wind has a great effect on the tidal movement of the waters of the bay and may produce irregularities in their behavior. The ocean tide has a mean range of 4.1 feet at Fire Island Breakwater. Because of the small size of Fire Island Inlet, the tidal wave is damped as it enters the bay. The range of tide is reduced consequently to less than 1 foot within the bay. The passage of the tidal wave is delayed by the narrowness of the opening and the shallowness of the bay. As a result high water occurs progressively later at points more remote from the inlet. It actually takes the tidal wave about 4 hours to pass from Fire Island Inlet to Bellport Bay.

The time of high water relative to Sandy Hook and the mean range of tide, based on the predictions of the U. S. Coast and Geodetic Survey (8) and supplemented by our present observations, are shown in Figures 5 and 6. The cotidal lines in the former figure represent successive positions of the crest of the tidal wave as it advances into the bay.

The tidal current due to the flow of water into and out of the bay are strong in the restricted passage of the inlet where maximum velocities of 3 knots occur. Within the bay, the velocities are small. In general the movement has an east-west direction paralleling the shores and results in a drift of about 1.7 miles in the course of each tide with maximum velocities of less than 0.5 knots. Floating dye markers placed in a number of positions along the bay have been traced throughout a complete tidal cycle. Those in the eastern part of the bay were found to take a somewhat elliptical course--moving eastward during the flood tide, tending to turn northward as slack water approached, then after assuming a westerly course during the ebb, tending southward as the slack terminated the ebb. This indicates that the water in the bay has a somewhat rotatory motion.

The course traced by the dye markers in various parts of the bay and the net movement of the water on the flood and ebb are shown in Figure 7.

Although the tidal wave takes some time in traversing the length of the bay, as shown by the delay in time of high water, slack water occurs at nearly the same time in all parts of the enclosure. At the inlet, the tidal wave has the character of a progressive wave, in which slack water occurs near half tide when the level within the bay and without is the same. Maximum flood and ebb currents occur at about the time of high or low water in the ocean--when the difference in levels within and without is greatest. At the head of the bay at Bellport, in contrast, the advance of the tidal wave is stopped by the land. The water continues to rise as long as the flood continues and slack water occurs near the time of high water. At intermediate positions, intermediate conditions obtain.

Tables I and II record the principal data for points within Great South Bay.

<u>Relation of Moriches Bay and South Oyster Bay to Great South Bay</u>. Since Great South Bay connects with South Oyster Bay and Moriches Bay, the relation of the tides in these embayments to that in Great South Bay is of importance. Because the tide rises almost simultaneously along the outer shore of Long Island, the tide tends to flood and ebb through the several inlets at about the same time. If the adjoining bays were of the same size and shape, the tidal movement from each would meet in the connecting passages and little exchange between the bays would result. Actually, however, the bays are of very different size and some exchange through the connecting passages is to be expected. The conditions in relation to South Oyster Bay have not been examined but the connection with Moriches Bay has been studied in some detail. It appears that because of the delay in the passages of the tidal wave up Great South Bay, the tide rises earlier at the eastern end of Narrow Bay than it does in Bellport Bay. The result is that the current flows westward past Smith Point during the period of flood tide, introducing a considerable volume of water from Moriches Bay into Bellport Bay. This situation proves to be of great interest in connection with the present problem and will be discussed in detail below.

TABLE I

Time of High Water Relative to Sandy Hook and Mean Range of Tide in Great South and Tributary Bays from C. & G. S. Tide Tables for 1950

	Lat. N.	Long. W.	Time of High Water h m	Mean Range of Tide
Fire Island Breakwater	40°37'	73°18'	-0 45	4.1
Democrat Point, Fire Island Inlet	40°38'	73°18'	-0 35	2.6
Oak Beach, Great South Bay	40°38'	73°17'	+2 25	0.7
Babylon, Great South Bay	40°41'	73°19'	+3 05	0.6
Elder Island, Great South Bay	40°39'	73°24'	+3 25	1.0
Amityville, Great South Bay	40°39'	73°25'	+3 20	1.2
Fire Island Light, Great South Bay	40°38'	73°17'	+1 05	0.7
Patchogue, Great South Bay	40°45'	73°01'	+3 35	0.7
Bellport, Bellport Bay	40°45'	72°56'	+4 00	0.8
Smith Point, Narrow Bay	40°44'	72°52'	+3 25*	0.37*

* From data collected by WHOI 25 July to 4 August 1950

TABLE II

Time of Maximum Flood Relative to High Water at Sandy Hook and Average Flood Velocity in Great South Bay and Tributary Bays from C. & G. S. Current Tables for 1950 and WHOI Observations in 1950*

	Lat. N.	Long. W.	Time of Maximum Flood h m	Average Velocity knots
Jones Inlet	40°35'	73°34'	-1 47	2.9
Fire Island Inlet, near Oak Beach	40°38'	73°18'	-0 02	2.3
Fire Island Inlet, near Oak Beach	40°38'	73°18'	-0 37*	2.4*
Fire Island Inlet, near Democrat Pt.	40°38'	73°17'	-1 07	2.3
Off Conklin Point, Great South Bay	40°40'	73°16'	-0 36*	0.34*
Off Champlin Creek, Great South Bay	40°41'	73°12'	-0 28*	0.26*
Off Nicoll Bay, Great South Bay	40°42'	73°07'	-0 13*	0.36*
Off Patchogue, Great South Bay	40°43'	73°01'	+0 07*	0.28*
Off Howell Point, Great South Bay	40°44'	72°57'	+0 32*	0.2*
Smith Point, Narrow Bay	40°44'	72°52'	+0 05* †	0.6* †
Moriches Inlet	40°46'	72°44'	-1 07	1.3
Ponquogue Bridge, Shinnecock Bay	40°51'	72°30'	-0 07	0.7
Shinnecock Inlet	40°51'	72°29'	-1 07	2.4

Several measurements in Moriches Bay yielded velocities of less than 0.1 kt.*

† Variable, dependent on strength and direction of wind.

The relation of South Oyster Bay to Great South Bay has not been studied in detail. The salinity of the water in the western part of Great South Bay is higher than that found elsewhere (see Figures 9 and 10). The current measurement made between Conklin Point and Captree Island showed that the water there drifted eastward during the period of flood tide. These observations suggest that relations similar to those found in Moriches Bay may exist and that there may be an important movement of water from South Oyster Bay into Great South Bay with flood tide.

Fresh Water Exchange. As the result of a balance between the rate at which fresh water is entering the bay, following precipitation as rainfall, and its removal through tidal action, the sea water in the bay is substantially diluted with fresh water. An estimate of the factors contributing to this balance is important since they reveal the rate at which the bay water is replaced by the tidal circulation and indicate on what conditions the salinity of the water depends.

Three sources of information on the quantity of water entering or leaving the bay are available. These are (1) the rainfall of the drainage area of the bay, (2) the gaged flow of the tributary rivers, and (3) the net movement of salt water through the inlets by tidal exchange.

The average rainfall for the region is 43.94 inches per year. The rainfall during the three months immediately preceding the survey was (6):

May	4.92	inches
June	2.98	"
July	3.38	"
Mean	3.76	inches per month or 45 inches per year

We may apply the latter value of 45 inches per year to the area of the watershed with assurance that it represents nearly average conditions of rainfall. We obtain:

	Area square miles	Total Precipitation million cubic feet per day
Drainage basin	252	75.6
Great South Bay	90	27.0
Total	342	102.6

River flow data for the major tributaries of the bay for July 1950 has been supplied by the Highway Department and is given in Table III together with the watershed area of each. From the total discharge and total areas, it appears that the river discharge per day is 0.0553 million

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TABLE III

Gaged flow of tributaries of Great South Bay - July 1950

River	Drainage Area square miles	Flow million cubic feet per day
Carmans River	71.0	1.676
Swan River	8.8	1.020
Patchogue River	13.5	1.527
Connetquot River	24.0	2.780
Penataquit Creek	5.0	0.364
Sampawams Creek	23.0	0.468
Santapogue River	7.0	0.265
Carlls River	35.0	1.880
Total	187.3	9.980

Mean flow per square mile = 0.0533 million cubic feet per day cubic feet per square mile of watershed. Applying these figures to the total drainage basin (252 square miles), the estimated flow to the bay is 13.9 million cubic feet per day.

<u>Tidal Exchange</u>. The exchange of water through Fire Island Inlet and past Smith Point was examined by making a series of current measurements at several stations across the channels during complete periods of flood or ebb tide. The measurements at Smith Point were made with current poles floating in the upper four feet of water and those at Fire Island Inlet in the upper twelve feet of water. These measurements were multiplied by 3/4 to correct for the frictional effects of the bottom and integrated to obtain the total flow of water through the channel. Samples of water were collected periodically and analyzed for salinity. From these analyses, the amount of fresh water mixed with sea water in the sample was estimated assuming the sea water to have had an original salinity equal to the maximum observed during the flood.

The results of this study are summarized in Tables IV and V.

In Fire Island Inlet approximately 2,000 million cubic feet flow in and out with each tide. The measurements vary from day to day but on the average the volume of ebb exceeds the flood by 31 million cubic feet per tide. The volume of fresh water estimated to escape during the ebb is 55.9 million cubic feet per tide. A considerable portion of bay water returns with the flood tide and as a result 32.4 million cubic feet of fresh water re-enters the bay. The average net loss of water from the bay was consequently 23.5 million cubic feet per tide or 47 million cubic feet per day.

Similar measurements at Smith Point, Table V, show a net movement of water eastward amounting to 19.7 million cubic feet per tide carrying a net volume of fresh water of 8.8 million cubic feet per tide or 17.6 million cubic feet per day out of Great South Bay toward Moriches Inlet.

The volumes of tidal flow vary considerably in this channel due to the piling up of water in Bellport Bay during periods of westerly wind and in Narrow Bay during easterly winds.

No estimate has been made of the exchange of fresh water between Great South Bay and South Oyster Vay. Neglecting this exchange we find the total loss of fresh water from Great South Bay by tidal exchange to be:

TABLE IV

Summary of Measurements of Tidal Flow at Fire Island Inlet

	Ebb (West)			Flood (East)		
Date	duration h m	total volume $\times 10^6$ cu.ft.	fresh water volume $\times 10^6$ cu.ft.	duration h m	total volume $\times 10^6$ cu.ft.	fresh water volume $\times 10^6$ cu.ft.
25 July	6 40	1905	41.0	6 50	2610	24.0
27 July	6 25	2030	76.3			
28 July	6 32	2040	58.6			
30 July	6 20	2020	44.1			
31 July	6 24	2060	59.6	4 58	1620	28.2
1 Aug.				4 58	1710	23.3
2 Aug.				5 48	2090	48.0
3 Aug.				5 53	1980	25.8
4 Aug.				5 35	1870	45.2
Average	6 28	2011	55.9	5 41	1980	32.4
Net Ebb Flow per Tide		31	23.5			
Net Ebb Flow per Day		62	47			

TABLE V

Summary of Measurements of Tidal Flow at Smith Point

Date	Ebb (East) duration h m	Ebb (East) total volume x10^6 cu.ft.	Ebb (East) fresh water volume x10^6 cu.ft.	Flood (West) duration h m	Flood (West) total volume x10^6 cu.ft.	Flood (West) fresh water volume x10^6 cu.ft.
26 July	5 02			5 10	33.5	11.6
27 July	5 02	36.0	12.7	4 48	41.0	13.4
28 July	6 00	63.5	22.2			
29 July	7 30	121.5	41.7			
30 July	7 48	121.8	37.8			
31 July	6 12	88.0	36.4			
1 Aug.	4 50	57.9	17.6	4 38	57.5	17.6
2 Aug.	4 30	45.9	12.4			
4 Aug.	6 54	162.5	43.1	5 35	94.5	25.3
Average	5 59	76.3	25.8	5 15	56.6	17.0
Net EASTWARD Flow per Tide		19.7	8.8			
Net EASTWARD Flow per Day		39.4	17.6			

Through Fire Island Inlet	- 47.0	million	cubic	feet	per	day
Past Smith Point	- 17.6	"	"	"	"	"
Total	64.4	"	"	"	"	"

This total agrees closely with the value of 66 million cubic feet per day estimated by Whipple.

In order to draw up a balance sheet for the fresh water exchange we may make use of the following relations:

(1) Rainfall - evaporation = loss by tidal exchange

(2) Loss by tidal exchange = river flow + ground water seepage

In making the calculations, the rain falling on the bay itself may be left out of account since in these latitudes, 40°N, rainfall and evaporation from the sea surface are approximately equal (7).

From the first equation:

Rainfall on drainage basin	= 75.6	million	cu.ft./day		
Loss by tidal exchange	= 64.6	"	"	"	"
Loss by evaporation	= 11.0	"	"	"	"

From the second equation:

Loss by tidal exchange	= 64.6	"	"	"	"
River flow	= 13.9	"	"	"	"
Ground water seepage	= 50.7	"	"	"	"

These estimates may be summarized as follows:

	million cu.ft./day	per cent
Rainfall on watershed	= 75.6	100
Evaporation from watershed	= 11.0	14.5
Ground water seepage	= 50.7	67.1
River flow	= 13.9	18.4
Loss by tidal exchange	= 64.6	85.5

The most striking feature of this tabulation is the great volume of ground water seepage relative to the river flow, a condition obviously related to the sandy character of the soil. Fresh water in substantial amounts must be entering the bay along its entire northern shore and changes in ground water level must be quite as important in freshening the bay as are the rates of flow through the river mouths. Figure 8, which is based on data supplied by

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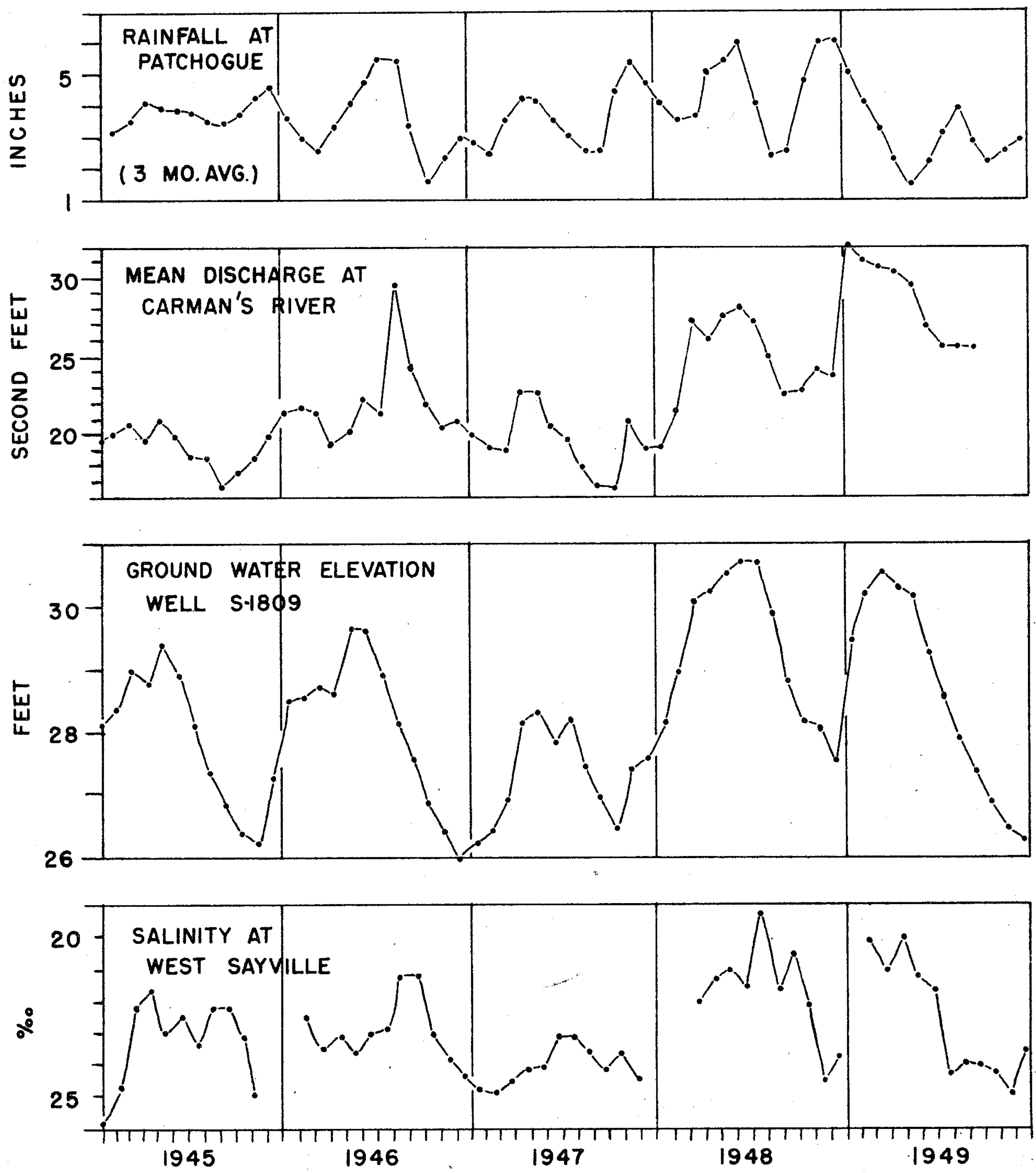

FIG. 8 MONTHLY RAINFALL, RIVER FLOW, GROUND WATER ELEVATION AND SALINITY OF BAY WATER DURING THE YEARS 1945 TO 1949

the Highway Department and the Bluepoints Company, shows the monthly trend in rainfall at Patchogue, the flow of the Carmans River, ground water elevation at Well S - 1809, which is 1.5 miles northwest of Bayshore, and the salinity of the bay water off West Sayville during the years 1945 to 1949. It is clear that the three latter conditions are closely correlated.

Flushing Time. The flushing time is the average time during which a molecule of water introduced into a bay by rainfall, runoff, or seepage remains in the bay. It may be estimated from data on the quantity of fresh water in the bay and the daily rate of movement of fresh water into or out of the bay.

From the salinity survey, it appears that the sea water entering Great South Bay contained 32 parts of salt per thousand. The salinity decreases eastward and northward from Fire Island Inlet to a minimal value of about 20 in Bellport Bay. The average value of all salinity measurements taken is 26 parts per thousand. Since these measurements were distributed systematically and there is little vertical variation in salinity, this value may be taken to represent the average salinity of bay water. The proportion of fresh water in the bay is consequently

$$\frac{32 - 26}{32} \times 100 = 18.7\%$$

The volume of the bay water is estimated to be 1,6700 million cubic feet. The amount of fresh water in the bay is consequently

$$\frac{18.7}{100} \times 1,6700 \text{ or } 3120 \text{ million cubic feet.}$$

Taking 65 million cubic feet as the daily movement of fresh water into and out of the bay, it appears that the flushing time is

$$\frac{3120}{.65} = 48 \text{ days, or about 96 tidal cycles.}$$

A flushing time of 48 days indicates that on the average fresh water entering the bay remains in the bay about seven weeks. Of course, much water moves out sooner but equivalent amounts, particularly that entering the eastern end of the bay remains there longer. This estimate

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is important in showing that conditions within the bay are influenced only very slowly by water from the ocean. Particularly, it shows that there is ample time for biological events, such as the setting of shellfish larvae or the growth of microorganisms, to take place undisturbed within the bay water.

Salinity Distribution. Salinity measurements taken at the surface, at mid-depth, and near the bottom are nearly the same at most positions in the bay except in or near the river mouths. See Table VI. This shows that the water is well mixed from surface to bottom.

The distribution of salinity at mid-depths is shown for high tide and low tide as measured between July 25 and August 3, 1950. See Figures 9 and 10. The general pattern is the same at both times, though there is some shift in the position of the isohalines chiefly in an east-west direction with the tide. In all parts of the bay, the fresher water is found on the north side. The freshest water is found in Bellport Bay and the water from there westward along the north side of the bay increases only slightly in salinity.

This distribution of salinity obviously is related to the position of the rivers along the shore. About 70 per cent of the river flow enters the bay east of Nicoll Point. There are theoretical reasons to believe that the distribution of salinity also reflects an asymmetry of the circulation due to the effect of the earth's rotation on the tidal movement. It is very commonly observed in estuaries that the water is freshest on the right side, as is the case in the eastern part of Great South Bay. (In describing estuaries, as in rivers, the sides of the channel are described relative to the direction of seaward motion.) This effect is interpreted to mean that more water is transported landward on the left side of the channel during flood tide and more seaward on the right side during the ebb. The result is a somewhat circular drift of the water in an anticlockwise direction which facilitates the flushing of the bay. Some evidence for such a movement was found in the eliptical course followed by drifting dye markers (Figure 7).

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TABLE VI

Vertical Distribution of Salinity and Oxygen at Various Places in July 1950

	At High Water			At Low Water		
	Depth feet	Salinity °/oo	Oxygen % sat.	Depth feet	Salinity °/oo	Oxygen % sat.
0.7 miles SE of Conklin Point	0	26.53	91.8	0	26.56	106
	5	26.55	89.8	4	26.62	107
	10	27.20	67.2	8	26.56	102
1.3 miles SSE of Green Point	0	24.14	101			
	6	24.24	102			
	12	24.20	98.0			
1 mile S of Blue Point	0	22.45	93.4	0	22.29	72.6
	6	22.85	90.2	5	22.77	72.0
	12	23.59	66.8	10	23.17	61.8
1 mile S of Blue Point	0	22.63	108			
	5	22.57	107			
	10	22.59	105			
0.6 miles S of Howell Point	0	20.19				
	4	20.19				
	8	20.25				
0.5 miles S of Fire Place Neck				0	20.19	95.4
				3	20.16	95.4
				6.5	20.26	97.3
In channel at Smith Point				0	23.77	98.4
				4	23.82	98.4
				8	23.78	97.6
In Patchogue River	0	17.86	126	0	10.52	44.2
	5.5	20.50	55.0	5	21.17	65.2
	11	20.50	40.1	10	21.44	71.0
In Forge River	0	19.20	149	0	12.09	8.0
	2	19.29	139	2	22.16	32.6
	4	19.98	136	4	27.07	15.0
In Seatuck Cove (Moriches Bay)	0	24.96	100	0	28.06	49.5
	2.5	26.55	99.7	2.5	28.17	49.5
	5	27.22	98.3	5	28.15	50.5

The deepest samples were collected from within one foot of the bottom.

IV. RECORDED CHANGES IN FACTORS RELATED TO THE CIRCULATION

Records, going back in some cases for more than fifty years, are available on several factors which are related to the tidal circulation. They throw some light on changes in circulation which may have accompanied the changes in the inlets. These include records of the height of tide and time of high water at several places, of the flow through Fire Island Inlet, and of the salinity of the bay water. In interpreting these records it may be assumed that, other things being equal, any reduction in the access of the sea to the bay will result in a decrease of the tidal range in the bay, greater delay in the time of high water, and a lowering of the salinity of the bay water.

Tidal Records. Measurements of the time of high water and the mean range of tide at several points in the bay have been recorded by the U. S. Coast and Geodetic Survey at times when they were engaged in survey work in the area. The predicted ranges, based on these records are published annually in the Tide Tables (8) from which the data presented in Table VII has been prepared. This table shows the predictions for Babylon, Patchogue, and Bellport, at which places the record is sufficiently long to be of interest. In inspecting this table it should be noted that the repetition of the same values year after year does not mean there has been no change, since the old values are carried in the tables until new measurements show them to be no longer correct.

The records show that the mean range of tide has been reduced 50 per cent in 66 years at Babylon, 30 per cent in 55 years at Patchogue, and 27 per cent in 60 years at Bellport. The time of high water, relative to the ocean tide as recorded at Sandy Hook, has also become later through the years. At Babylon the interval has increased 36 minutes in 66 years, at Patchogue 23 minutes in 55 years, at Bellport 40 minutes in 60 years.

These observations are interpreted to mean that a restriction in the inlets has resulted in a reduction of the amount of sea water which enters and leaves the bay during each tidal cycle and in a delay in the passage of the tidal wave into the bay. The critical change appears to have occurred between 1916 and 1930.

The velocity and excursion of the tidal currents in the bay recorded by Whipple in 1907-08 may also be compared with the measurements made during the past summer. The recorded velocities are shown in Table VIII. While the points of observation are not quite the same it is significant that the average velocity was 50 per cent greater forty years ago

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TABLE VII

Mean Range of Tide and Time of High Water relative to Sandy Hook since earliest record, from predictions of the U. S. Coast and Geodetic Survey

	Babylon		Patchogue		Bellport	
Year	Mean Range feet	Time of High Water h m	Mean Range feet	Time of High Water h m	Mean Range feet	Time of High Water h m
1884	1.2	+2 20				
1890	1.2	2 09			1.1	3 08
1895	1.2	2 17	1.0	3 04	1.1	3 21
1916	1.2	2 12	1.0	3 00	1.1	3 17
1930	0.9	2 12	0.7	3 27	0.7	3 42
1936	0.6	2 56	0.7	3 27	0.8	3 48
1950	0.6	2 56	0.7	3 27	0.8	3 48
Change since first prediction	0.6 50%	36 minutes	0.3 30%	23 minutes	0.3 27%	40 minutes

TABLE VIII

Average Velocity of Tidal Currents at Various points in Great South Bay

	1907-08	1950
Off Lindenhurst	0.31 kts	
Off Babylon	0.71	
Between Conklin Pt and Captree Island		0.34 kts
Off Bayshore in West Channel	0.65	
Off Champlin Creek		0.26
Off Nicoll Point	0.60	
Off Nicoll Bay		0.36
Off Blue Point	0.24	
South of Patchogue		0.28
Near Howell Point	0.35	0.2
Near W. of Carmans River	0.17	___
Average	0.43	0.29

than today. Whipple states that the average excursion was 3.3 miles on the ebb and 2.25 miles on the flood. The measurements made in 1950 indicated the average excursion to be 1.7 miles. Thus, these data also indicate a decrease in the circulation in recent years.

<u>Flow at Fire Island Inlet.</u> Whipple made two sets of measurements of the current in Fire Island Inlet in 1907. The estimated flows obtained were:

October 21	- 1954	million	cubic	feet	on	flood
	- 1948	"	"	"	"	ebb
December 7	- 2020	"	"	"	"	flood
	- 1640	"	"	"	"	ebb
Average	1890	"	"	"	"	per tide

The U. S. Engineers made current observations in Fire Island Inlet between September 11 and 20, 1940. It was estimated that the mean flows were (6):

	1846	million	cubic	feet	on	the	flood
	2405	"	"	"	"	"	ebb
Average	2126	"	"	"	per tide		

These measurements are close to those obtained in July 1950 and recorded in Table IV, which yielded a mean value of 2011 million cubic feet per tide. They afford no indication that the exchange of water through this inlet has changed in the last forty years.

<u>Salinity Changes.</u> Whipple's report quotes some observations on the specific gravity of bay water off Blue Point made by Bashford Dean in 1886. On converting Dean's and Whipple's figures to salinities they may be compared with the measurements made in July 1950 as follows:

Year	Observer	Salinity off Blue Point: Mean	Salinity off Blue Point: Range
1886	Dean	14.2 ‰	11 - 18 ‰
1907-08	Whipple	22 ‰	
1950	W.H.O.I.	23 ‰	22.6-23.5

This data indicates that off Blue Point there has been an increase in salinity at Blue Point, amounting to more than 50 per cent in the course of sixty-four years. The greatest change occurred prior to 1907.

An excellent weekly record of the salinity at West Sayville has been kept by Mr. Glancy of the Bluepoints Company since March 1933. Table IX shows the average value for each year and the departure of the yearly average from the average for the entire series. It is clear from this table that there has been no progressive change in the average salinity off West Sayville during the past seventeen years.

Whipple made extensive surveys of the distribution of salinity in Great South Bay during November-December 1907 and in July 1908. He noted that the salinities were higher at the latter time, particularly in the east end of the bay, although the general pattern was similar at both periods. In order that his results might be compared with these obtained in July 1950, Whipple's figures (8, Sheet 126) based on all determinations made during the investigation of 1908 are reproduced in Figure 11. Whipple's isochlors have been relabeled to show the corresponding salinity values.

Whipple's observations differ from the present conditions in two principal ways: (1) the salinity was more nearly equal on opposite sides of the bay, as shown by the more nearly transverse slope of the isohalines, and (2) the bay was salter at the western end and very much fresher at the eastern end. The latter difference is brought out clearly by Figure 12 which shows the change in salinity observed between 1908 and 1950.

At the longitude of Nicoll Bay, the salinity was about the same at both periods. To the west the salinity is now somewhat (1 - 2 $^{o}/_{oo}$) lower than in 1908. This change may be due to the closing of Gilgo Inlet which was open in 1908, or it may merely reflect seasonal variations in rainfall. In the eastern end of the bay the salinity is higher than formerly. The difference increases as the channel into Moriches Bay past Smith Point is approached. At Smith Point the salinity has increased from 12 to 23, a difference of 11 parts per thousand. There is no doubt that this change is related to the opening of Moriches Inlet, which occurred in 1931.

Since the change in salinity in the eastern end of Great South Bay is the most striking alteration of which there is record, and as the exchange of water between Moriches and Great South Bay will appear to be important in connection with the findings of the next section, it will be discussed in some detail.

TABLE IX

Yearly Average Salinity of Bay Waters at West Sayville - 1933 to 1949

Year	Yearly Average °/oo	Departure from Mean °/oo	Year	Yearly Average °/oo	Departure from Mean °/oo
1933	23.8	+0.5	1942	23.0	-0.3
1934	22.7	-0.6	1943	24.0	+0.7
1935	23.9	+0.6	1944	24.0	+0.7
1936	22.7	-0.6	1945	23.3	0
1937	23.6	+0.3	1946	22.9	-0.4
1938	21.8	-1.5	1947	24.0	+0.7
1939	23.1	-0.2	1948	21.6	-0.7
1940	23.6	+0.3	1949	23.0	-0.3
1941	24.7	+1.4			

Mean		
1933-49	23.3	
Extreme departure of yearly average from mean		+1.4 - 1.5

At the time of Whipple's survey in 1907-08 Moriches Inlet was closed and Shinnecock Bay was open permanently to the ocean only through Shinnecock Canal. The salinity was 10 ‰ in Moriches Bay, 18 ‰ in Shinnecock Bay and 12 ‰ in the eastern end of Great South Bay. Fresh water draining into Moriches Bay occupied two-thirds of its volume. Some movement of fresh water into Shinnecock Bay from Moriches Bay may have occurred, but probably it was small to judge from the narrowness and length of the channel and the relatively high salinities in the western end of Shinnecock Bay. The greater part of the fresh water falling on the Moriches Bay watershed must have found its way to sea past Smith Point and through Great South Bay.

In 1907-08 high water occurred at Smith Point about 3½ hours after Fire Island, as it then did at Bellport. The current at Smith Point turned east at about half tide and reached maximum velocities at about high water, as shown in Figure 13 based on Whipple's observations. Thus, the tidal wave which progresses eastward in Great South Bay continued on its course into Moriches Bay. The salinity of the water flowing westward out of Moriches Bay was nearly 2 ‰ fresher at the end of the ebb, than that flowing eastward with the flood tide, and thus a net transport of fresh water from Moriches into Great South Bay was affected.

At the present time as the result of the opening of Moriches Inlet, the rising tide flows through Moriches Inlet to raise the level in Moriches Bay. It will be recalled that the crest of high water reaches Bellport four hours after high water at Fire Island Breakwater. Because of this delay the water level rises earlier in Moriches Bay than in Bellport Bay and the current flows westward past Smith Point during the flood. Slack water occurs about three hours after high water at Sandy Hook or one hour before high water at Bellport. The time relations during the entire tidal cycle are illustrated in Figure 13 where they may be compared with these obtaining in 1908.

The tide in Narrow Bay may be approximately accounted for if it is considered to be due to the simple hydraulic flow occasioned by the difference in level between the ocean off Moriches Inlet and the water in Bellport Bay.

The average volume of water moving past Smith Point during the flood was determined to be 56.6 million cubic feet per tide. If it is assumed that the water in Bellport Bay rises 0.6 feet on the average the flow from Moriches Bay is sufficient to produce this rise over an area of 94 million square feet or 3.8 square nautical miles. This is

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about 2/3 the area of Bellport Bay. It is concluded that the tidal waves entering Fire Island and Moriches Inlets meet in the western part of Bellport Bay. This region may be expected to have very small tidal currents. It is possible that the slight increase in the range of tide predicted for Bellport after 1930 (see Table VII) is attributable to this meeting of the opposing tidal movements.

The salinity of the water in Moriches Bay now ranges from 23 to 20 $^{o}/_{oo}$ depending on the stage of tide and position relative to the inlet. These are higher values than obtain in Bellport Bay. As a result of this difference, and the excess flow of water eastward during ebb tide (see Table V) there is a net movement of fresh water from Bellport to Moriches Bay. This movement is estimated to amount to 18.7 million cubic feet per day. It thus exceeds the measured river flow into Great South Bay and is equal to a fourth of the estimated total addition of fresh water due to rainfall on the watershed. It thus accounts for the increase in the salinity of the eastern end of Great South Bay since the time of Whipple's study.

<u>Summary</u>. The evidence on the changes in hydrographic conditions during the past years is not completely consistent and the records are fragmentary. However, the recorded tidal observations indicate that there has been a decrease in the tidal circulation in the bay which took place prior to 1930. While the current measurements in Fire Island Inlet show no change in flow since 1907, these estimates depend on rather elaborate calculations and one cannot be sure that the results are strictly comparable. They also fail to take account of the changes in circulation which may have followed the closure of Gilgo Inlet. It is quite clear that the opening of Moriches Inlet in 1931 has been followed by a marked change in the pattern of circulation in the eastern end of the bay with attendant changes in the salinity of the water.

The decline in oyster production which became marked in the early thirties appears to be associated with the local changes which followed the opening of Moriches Inlet rather than with the general decline in tidal exchange which according to the record occurred chiefly at an earlier period.

V. EVIDENCE OF POLLUTION

Pollution by organic matter may be expected to manifest itself by an increase in the nitrogen and phosphorous content of the water. The interpretation of the findings is not simple since these elements when first discharged into the water may be combined with organic matter and will not respond to the usual tests. Decomposition of the organic matter releases the elements as simple inorganic molecules; as phosphate, ammonia, nitrite, nitrate, and carbonic acid. These inorganic materials are the natural food of marine plants and may be absorbed by the plants as rapidly as they are set free. Consequently, a rather elaborate set of measurements must be made to obtain the correct picture of what is going on.

The oxygen content of the water and the pH are also influenced by the chemical and biological events which accompany pollution. In the decomposition of organic matter, oxygen is consumed and the pH may fall due to the production of carbon dioxide and other acid products. On the other hand, the growth of plants, which is stimulated by the presence of phosphate and nitrogen compounds is accompanied by the liberation of oxygen and an increase in the pH of the water. Exchanges in oxygen and carbon dioxide with the atmosphere also take place through the surface of the water, and may obscure the effect of pollution on these substances. Great care must consequently be taken in interpreting the data.

<u>Phosphorous Compounds</u>. The distribution of total phosphorous in the water of Great South and Moriches Bay is shown in Figures 14 and 15. These measurements include the phosphorous present as inorganic phosphates, and the phosphorous contained in living cells or in organic compounds dissolved in the water. Throughout the greater part of Great South Bay, the total phosphorous is present in amounts between 4 and 5 microgram atoms per liter. This is about three times the quantity in the sea water entering Fire Island Inlet. Smaller quantities are found in the western part of Great South Bay. In Moriches Bay, the total phosphorous is higher, being everywhere in excess of 5 microgram atoms and increasing markedly in the mouths of the Forge River and Seatuck Creek and off Speonk River. Concentrations in excess of 5 microgram atoms per liter were also found throughout Bellport Bay at low water with greatest values at the mouth of the Carmans River.

These measurements point to an excessive pollution of Great South Bay with organic matter--the quantities of phosphorous found being more than twice that usually expected in coastal embayments. The higher concentrations at the mouths

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of the principal tributaries to Bellport and Moriches Bays point to these streams as the source of pollution.

The concentration of inorganic phosphate throughout the bays is shown in Figures 16 and 17. It is very clear that the greatest concentrations occur in Moriches Bay and its tributaries with lesser concentrations off Carmans River and Patchogue Creek. The lower values found throughout the greater part of Great South Bay indicate that there much of the phosphate has been absorbed by marine plants. At some positions in the Forge River, the inorganic phosphorous exceeds the values obtained for the total phosphorous. This is due to difficulties in sampling and in the analysis of phosphorous at such high concentrations.

The amount of phosphate phosphorous absorbed and bound as particulate matter, consisting of microscopic plants, bacteria and detritus, is shown in Figures 18 and 19. A similar distribution is obtained by the difference between the total phosphorous and that present as inorganic phosphate, the so-called bound phosphorous, shown in Figure 20. The highest values extend from Bellport to Nicoll Point. This distribution is paralleled by the transparency of the water shown in Figure 21. These measurements all reflect the number of microscopic plants in the water and their distribution.

It is noteworthy that a large amount of phosphate remains in the water in the presence of such a dense population of microscopic plants. Usually such heavy growths remove the phosphate completely from the water. It should also be pointed out that there is relatively little bound phosphate in the waters of Moriches Bay, where the total quantity of phosphorous compounds is greatest. This fact indicates that the phosphorous compounds there have not yet been absorbed by plants and accords with the relative clarity of Moriches Bay water. Discussion of these facts will be deferred until the data on nitrogen compounds has been presented.

Nitrogen Compounds. Samples of water from many parts of the bays were examined for the presence of ammonia, nitrite and nitrate.

The ammonia analyses were uniformly negative or showed only the presence of traces. The method is sensitive to 1 microgram atom of ammonia nitrogen per liter.

Nitrite could not be detected in most of the samples. A few samples from the part of the bay west of Cedar Island contained about 0.10 microgram atoms of nitrogen per liter as nitrite. Values of this magnitude were also obtained from the Connetquot and Carmans Rivers.

Nitrate, which is usually the most abundant form of nitrogen in natural waters, was also absent or present in concentrations less than 0.1 microgram atoms of nitrogen per liter in most of the samples. Samples of sea water entering Fire Island Inlet contained as much as 4 microgram atoms while one sample from the approach to South Oyster Bay contained as much as 8 microgram atoms per liter. Samples from the mouths of the Carmans and Forge Rivers also contained one or more microgram atoms of nitrate nitrogen per liter.

These observations are most surprising since the large quantities of phosphorous compounds present in the water might be expected to be accompanied by even greater amounts of nitrogen compounds if the condition is due to organic pollution. Living matter commonly contains about 15 or 20 atoms of nitrogen for every atom of phosphorous, and the same is usually true of sea water in which materials of biological origin have decomposed. Consequently, the total nitrogen in the bay water might be expected to amount to 50 or 100 microgram atoms per liter.

An attempt is now being made to develop a satisfactory method for determining the total nitrogen content of sea water samples, with a view to measuring the quantities of nitrogen present in organic combination.

<u>Discussion of Phosphorous and Nitrogen Distribution.</u> The distribution of phosphorous has pointed to the Carmans and Forge Rivers and Seatuck Creek and hence to the duck farms on those rivers as the probable source of pollution. The relative deficiency of nitrogen in the water, as indicated by the measurements made, finds a ready explanation when it is considered that the duck farms are concentrated on the shores of these streams and that ducks excrete nitrogen in the form of uric acid. Uric acid is not detected by the methods employed in the survey and the expected amounts of nitrogen may have been present in this form.

This hypothesis may account for the relative clarity of the water of Moriches Bay. Uric acid is a relatively stable substance which probably cannot be assimilated by plants until it has been decomposed by bacterial action to ammonia and carbon dioxide[1]. There are relatively few bacteria in natural waters capable of performing this trans-

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[1] An experiment conducted by Mr. George Van der Borgh, Jr. has indicated quite clearly that the "small form" does not use uric acid as an immediate source of nitrogen.

formation. Consequently, it is probable that in Moriches Bay much of the nitrogen is present in a form which cannot be assimilated by plants and consequently the plant populations remain limited. On the other hand, the water remains in Great South Bay for a relatively long time permitting bacterial action to make the nitrogen of uric acid available.

It may further be suggested that the failure of the plant populations in Great South Bay to exhaust the phosphate present in the water is due to a deficiency in nitrogen which actually limits their further growth. In support of this view, Dr. Lackey has suggested that the yellow color of the bay water may be due to chlorosis--a characteristic failure to develop normal quantities of chlorophyll which many plants show if deprived of sufficient nitrogen.

The excreta of a duck secured during the survey and fed on the customary diet showed on analysis a content of 3.9% nitrogen and 2.73% phosphorous. This represents a ratio of about 3 atoms of nitrogen to 1 of phosphorous. Green algae normally require 15 or 20 atoms of nitrogen for each atom of phosphorous absorbed during growth, although they can grow when smaller proportions of nitrogen are available. It is evident that if the unusual fertility of the water is due to pollution by duck manure, the growth may finally be held in check by a shortage of nitrogen.

Measurements of the total phosphorous in samples of water collected at West Sayville during the first half of 1950 have been supplied by the New York Conservation Department's laboratory at Freeport. They show that, during the winter, the phosphorous content of the water has low values, which increase after April first and become very high during July (Figure 22). This data indicates that the pollution responsible for the abnormal phosphorous content of the bay water is seasonal in character. It supports the view that the duck farms are responsible for the condition since the population of the farms is commonly reduced greatly during the winter. The summer's crop of ducks begins to grow in April.

Simultaneous measurements of the numbers of small forms in the water are also shown in Figure 22. It may be seen that their numbers increase rapidly in June and July, thus paralleling the accumulation of phosphorous in the water.

Oxygen Saturation. The state of the bay water with regard to oxygen saturation at mid-depths is shown in Figures 23 and 24. In the central section of Great South Bay, the

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oxygen saturation is highest ranging between 80 and 100 per cent saturation. The values are somewhat lower in the western arm and fall markedly in Bellport Bay and in Moriches Bay at low tide.

The saturation values at different depths for a number of positions are shown in Table VI. In most cases, the samples taken close to the bottom have lower values--between 60 and 70 per cent saturation--than at the surface or at mid-depths. In the samples taken in the Forge River and in Seatuck Cove, saturation values varying from 50 to 15 per cent were observed at low tide.

The oxygen values obtained were very variable when observed repeatedly at the same position. This may be due to the rapid production of oxygen by photosynthesis by the great population of algae present whenever conditions of illumination were favorable. Thus, the results would vary with the time of day at which the measurements were made. It is also probable that because of the turbidity of the water the light intensity is reduced near the bottom to values at which the plant cells are unable to carry on photosynthesis and that there oxygen is being consumed by the plants.

The important conclusion which may be drawn from the oxygen data is that the supply of oxygen is inadequate to keep the water fully saturated. While the values rarely fall below 50 per cent--which is frequently considered to be the critical value in setting up standards for the pollution of streams--it frequently approaches this value near the bottom. It is not known whether such low values are undesirable for the cultivation of shellfish.

Hydrogen potential, (pH). Systematic measurements were made of the pH value of the bay water at high and low tide, (Figures 25 and 26). In the central part of Great South Bay and in the Forge River at high water, values as high as 8.5 - 8.7 were obtained. These values are abnormal but may be explained as due to the intensive absorption of CO_2 by the great population of plant cells. In the western area of Great South Bay, the pH values were abnormally low--pH 7.6--which may point to domestic pollution in that area.

Iron. Analyses were made of the iron content of the water throughout the bay. The distribution was very irregular and probably points to the location of rusting wrecks, bulkheads, etc. Since the results cannot be interpreted usefully in relation to the problem, they are not reported.

Discussion. The unusual quantities of phosphorous in the water of Great South Bay and the somewhat reduced oxygen content of its water indicates that excessive organic

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pollution is present. The source of the phosphate appears to be the Carmans River and the tributaries of Moriches Bay and by inference may be due to the duck farms concentrated along those streams.

There is evidence that the pollution is seasonal in character, increasing to abnormal amounts in the early summer at about the time when the season's crop of ducks begins to grow. The supposition that the condition is due to the duck farms also explains the failure of the methods employed to demonstrate the expected quantities of nitrogen compounds in the water, since ducks excrete nitrogen as uric acid--a compound not detected by the methods employed.

The study of the circulation of Narrow Bay showed that a substantial exchange of water takes place between Moriches and Bellport Bay. As a result of this exchange, salt water moves from Moriches to Bellport Bay. It may be inferred that this exchange would also carry pollutants in the same direction. The tributaries of Moriches Bay would thus contribute to the pollution of Great South Bay.

The relation between the pollution and the great population of marine algae is obvious since great quantities of phosphorous and nitrogen are required to produce such a large number of plant cells. It has been shown that in the central part of Great South Bay where the numbers of "small forms" is greatest, the amount of inorganic phosphate has been greatly reduced. It also appears that this population increases rapidly in early summer when larger quantities of phosphorous become available.

It remains to be considered whether the small forms are in fact responsible for the recent decline in the oyster production of Great South Bay. There are two points to be made in this regard. First, there is evidence from experiments by Loosanoff and Engle (3) that high concentrations of marine algae interfere with the feeding of oysters. They placed the critical concentration for chlorella at 2 million cells per cc--which concentration is frequently exceeded by the "small forms". Second, it appears that the small form was first noted in Great South Bay at about the time production of market oysters began to decline in the early thirties. Moreover, there appears to be a correlation between good and bad oyster years--as judged by the pints of meats per bushel of oysters and the number of small forms in the water. This relation is shown in Figure 27 which is based on records supplied by Mr. Joseph B. Glancy.

In summary, the evidence appears to be substantial, though circumstantial, that the failure of oyster production

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in Great South Bay is due to pollution from the duck farms along the tributaries of Bellport and Moriches Bays.

VI. REMEDIAL MEASURES

The facts which have been brought to light by the survey of Great South Bay and by accessory information secured during its progress indicate that the present unsatisfactory condition of the bay for the production of market oysters is the result of excessive pollution by organic matter. The state of pollution depends, of course, on the balance between the rate at which pollutants are added and their removal by the circulation of water. This balance may be altered by changes in either of these factors.

While there is evidence that changes in the inlets have restricted the exchange of bay water with the ocean somewhat, these changes seem to have occurred prior to the decline of the market oyster industry. There appears to be no reason why the bay should not again become a favorable environment for the growth of oysters, if the effects of the excessive pollution could be removed. The salinity over the greater part of the oyster beds has not changed notably and the tidal currents are sufficient to keep the water from stagnating. Since the water remains in the bay nearly two months on the average, it is probable that exchanges with the ocean have little effect on its oxygen content. In such a shallow bay, sufficient oxygen should be absorbed from the atmosphere under the influence of stirring by tide and wind to keep the water adequately oxygenated, if the excessive growth of microscopic life, due to organic pollution, were kept in check.

These remarks apply to the production of market oysters which were planted until recently along the entire length of the bay. The production of seed oysters occurred chiefly in the eastern end of the bay where formerly the water was very much fresher. The opinion is widely held that relatively brackish water is favorable to the production of seed oysters, in contrast to the growth and fattening of market oysters. We have seen that the salinity of Bellport Bay increased markedly following the opening of Moriches Inlet and this factor might have resulted in the failure of seed oyster production even in the absence of pollution.

Returning to the more general problem, it would seem more effective and economical to attempt to reduce the pollution, rather than to compensate for its excess by enlarging the openings in the beaches. To obtain the desired results, it would probably be necessary to increase the exchange of water with the ocean two or three times. The requisite channels and jetties would be prohibitively expensive and their effectiveness and permanence would be uncertain. In addition, they would not restore the circulatory conditions and the low salinity in the eastern end of Great South Bay which formerly appeared to favor seed oyster production.

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Since there is no evidence that the pollution is due to excessive contamination by domestic sewage, it appears that the situation would be corrected if the manure from the duck farms could be prevented from reaching the water of the bays. A recent study by the New York State Conservation Department (1) has considered the hazard of bacterial contamination of adjoining waters by the duck farms along the Peconic River and has described a method by which such contamination may be eliminated. The method proposed would not solve the present problem if the mineral content of the manure ultimately reached the water and became available to stimulate the excessive growth of marine algae. Any procedure which kept the excretions out of the water altogether would, however, eliminate the danger of bacterial contamination as well as improve the conditions of the bays water.

While no investigation has been made of the matter, it seems that duck manure might become a valuable by-product of the duck industry, which, if it did not yield a profit, might at least pay for the costs of preventing the pollution of the bays. The excretions of birds are valuable as agricultural fertilizers. Poultry manure is the richest of the animal manures commonly used, containing 1% nitrogen, 0.8% phosphorous and 0.4% potassium. The sample of duck manure examined by us contained almost four times these proportions of nitrogen and phosphorous. For more than a hundred years, the natural deposits of excrement from sea birds have been collected from their nesting colonies off the Peruvian coast and have been shipped all over the world for use as fertilizers. The yield of Peruvian guano, as late as 1937, was 150,000 tons. Allowing 2 pounds per duck per season, 5,000 tons of manure are being produced by the duck industry of Long Island each year.

While this expedient might be expected to improve conditions in the bay as a whole and thus lead to a restoration of market oyster production, it would not restore the special salinity conditions in Bellport Bay on which seed oyster production supposedly depends unless Moriches Inlet were to be permanently closed. If this were done also, however, the conditions in Great South Bay might be expected to be restored very nearly to those obtaining prior to 1930.

A third method of improving the conditions in Great South Bay would be to prevent the exchange of water between it and Moriches Bay. A proposal is now under consideration to build a roadway across the narrows at Smith Point to give access to Great South Beach. The construction would consist of a filled embankment with an opening sufficient to permit the exchange of tidal waters and spanned by a drawbridge. At additional expense, the opening might be filled completely except for a lock for the passage of boats along the intercoastal waterway. Such a construction would completely eliminate or place under control the movement of water between the bays.

Measurements have shown that the exchange of water between the two bays is substantial and there is no doubt that the more highly polluted waters of Moriches Bay reach Bellport Bay and return only in part with the ebb tide. There is reason to believe that at times of strong easterly winds the movement of water into Great South Bay is much greater than that indicated by the measurements. We understand that about ten times as many ducks are raised on the tributaries of Moriches Bay as on the Carmans River. The closure of the channel at Smith Point would eliminate any effects due to the farms in the Moriches Bay region and leave only the relatively few farms of Carmans River as a source of pollution. Quite possibly the pollution from this river would not be sufficient to maintain the present undesirable conditions in Great South Bay.

Considering other conditions which would follow the closure of the narrows at Smith Point, it may be anticipated that the range of tide in Bellport Bay might increase by a few tenths of a foot. The important change would be in a reduction of salinity in that region. It has been shown that a substantial quantity of fresh water now escapes from Bellport Bay into Moriches Bay as the result of the tidal movement. This water would be retained in the eastern end of Great South Bay and would reduce the salinity. The conditions probably would not return to those observed by Whipple in 1907-08, since at that time the fresh water sources of Moriches Bay passed seaward through Great South Bay. These sources are relatively small however. Measurements of the flow of Seatuck Creek, Terrell River, and Forge River made in 1907 gave a combined flow of only 1.14 million cubic feet per day as compared with 4.8 million cubic feet per day for the Carmans River (5). The drainage area of Moriches Bay is 52 square miles, compared with a combined area of 93 square miles for the Carmans, Swan and Patchogue Rivers. It might be anticipated from these data that the salinity in Bellport Bay would drop from the present value of 22 $^{o}/_{oo}$ to about 16 or 18 $^{o}/_{oo}$, in contrast to a value of 14 $^{o}/_{oo}$ obtained in 1907. On the assumption that low salinities favor seed oysters, this would be a substantial improvement.

The closure of the narrows at Smith Point would also have effects on Moriches Bay. The entire pollution from the Forge River and other tributaries would accumulate in Moriches Bay in amounts depending on the size of Moriches Inlet. The closure of the inlet would undoubtedly lead to objectionable conditions and a deterioration of recreational values, since the bay water would become nearly fresh and would support a heavy growth of algae. The stabilization of Moriches Inlet

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or the elimination of the present sources of pollution would be an almost necessary correlary of the closure of the narrows. There would be some increase in tidal range, depending in amount on the size of the inlet. If the inlet were stabilized at its present size, the average height of tide at high water would probably not increase more than 2 or 3 inches. The tidal flow, for a given size inlet, would decrease by perhaps 30 per cent if the flood waters were no longer drawn off into Bellport Bay.

Remedial measures are inescapably expensive. In balancing their costs against the benefits, the value of the oyster industry alone should not be taken into consideration. As "outsiders" from a region supported by its vacation business, we have been impressed with the potential values of Great South Bay and Moriches Bay as recreational assets. We have also been impressed by the relatively limited advantage being taken of this resource. The turbid condition of the bay water does not add to its attraction for boating and bathing. The reduction in pollution might do much to clean up the water and to make the area more attractive to vacationists. It might thus bring a return which would be greatly to the public interest.

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VI. ADDITIONAL INFORMATION DESIRED

The conclusions presented in the foregoing report should be regarded as tentative in that several questions have arisen as the result of the survey which were not anticipated and on which more information is desirable. In particular, the results obtained focus attention on the exchange of water between Bellport and Moriches Bays and the attendant transport of pollutants. The suspected presence of nitrogen in the form of uric acid presents new problems in sea water chemistry which to our knowledge have not been studied previously and for which suitable methods will need to be developed. If such methods are perfected, they should yield compelling evidence on the part the duck farms play in the pollution of the bays.

The following additional studies are desirable:

1. The determination of the uric acid content of the water of Great South Bay, Moriches Bay and their tributaries.

2. Additional measurements of tidal behavior including height and time of tide and current drifts in Moriches and Bellports Bays.

3. Additional measurements of the exchange between Moriches and Bellport Bays with particular relation to the transport of pollutants and the effect of winds on such transport.

4. Measurements to determine the amount of pollutants discharged by the Carmans River.

5. Studies of the rate of breakdown of uric acid by marine bacteria.

6. Investigation of the growth of "small forms" in relation to concentrations of nitrogen salts and phosphate, and in particular, to uric acid.

7. Study of the oxygen production and consumption in bay water containing small forms in relation to depth.

The New York State Conservation Department should continue its periodic determination of the concentrations of total phosphorous and numbers of small forms in the bay water throughout the year. Observations made in Bellport Bay in addition to Sayville during the spring and early summer would throw light on the origin of the abnormal phosphorous content of the water since it should increase first near the point of origin. Parallel determinations of the inorganic phosphate in the water would increase the interest of these data.

While the information may have limited bearing on the practical problem as it now appears, it would be desirable to make some study of the exchanges between Great South Bay and South Oyster Bay. Such information would round out knowledge of the present conditions and might prove of value for future reference.

The question of the salvaging of duck manure and its use for fertilizer might well be referred to the New York State Department of Agriculture for study. Consideration of the implications of a filled dyke and lock at Smith Point and the stabilization of Moriches Inlet are matters for the Suffolk County Highway Department to consider.

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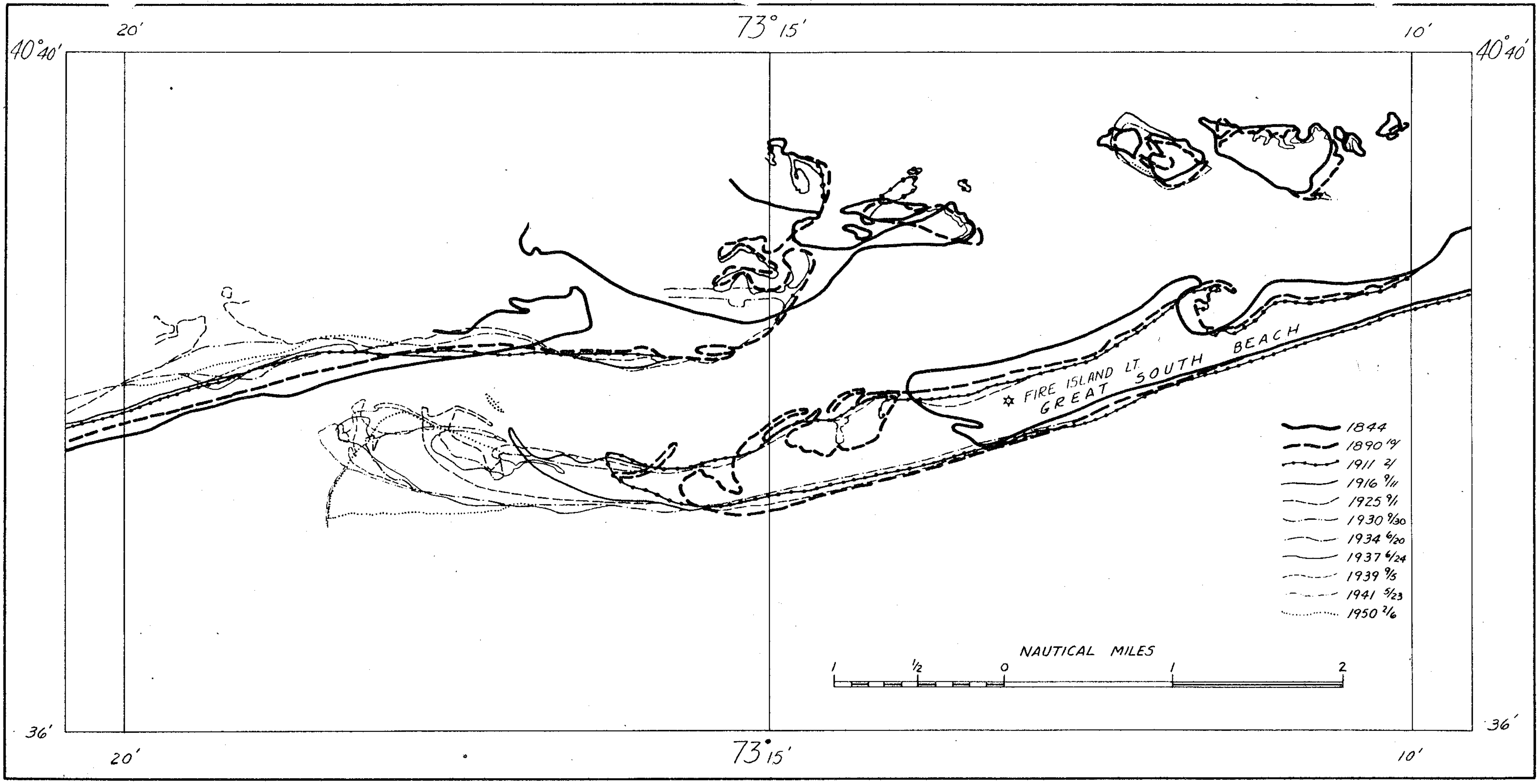

FIG. I DIAGRAM SHOWING WESTWARD GROWTH OF GREAT SOUTH BEACH AND LENGTHENING OF FIRE ISLAND INLET. FROM ALL EDITIONS OF U.S.C. AND G.S. CHARTS NO. 119 (1844 TO 1911) AND NO. 578 (1916 TO 1950)

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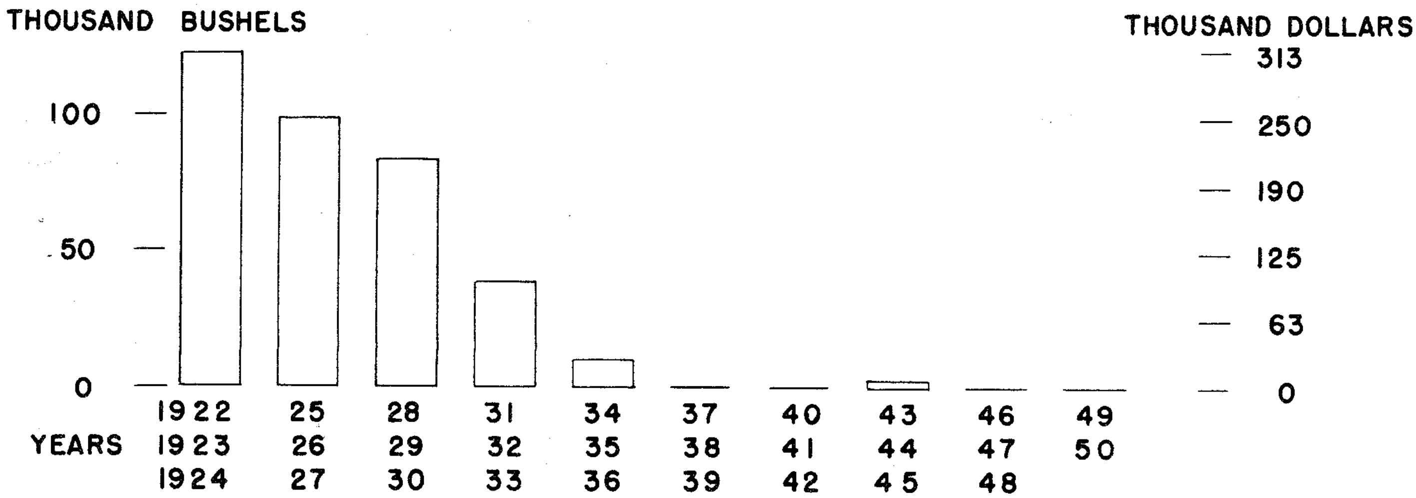

FIG. 2 SEED OYSTER PRODUCTION IN GREAT SOUTH BAY (PLOTTED AS 3 YR. AVERAGES)
FROM DATA COMPILED BY N.Y.S CONSERVATION DEPT., BUREAU OF MARINE FISHERIES.

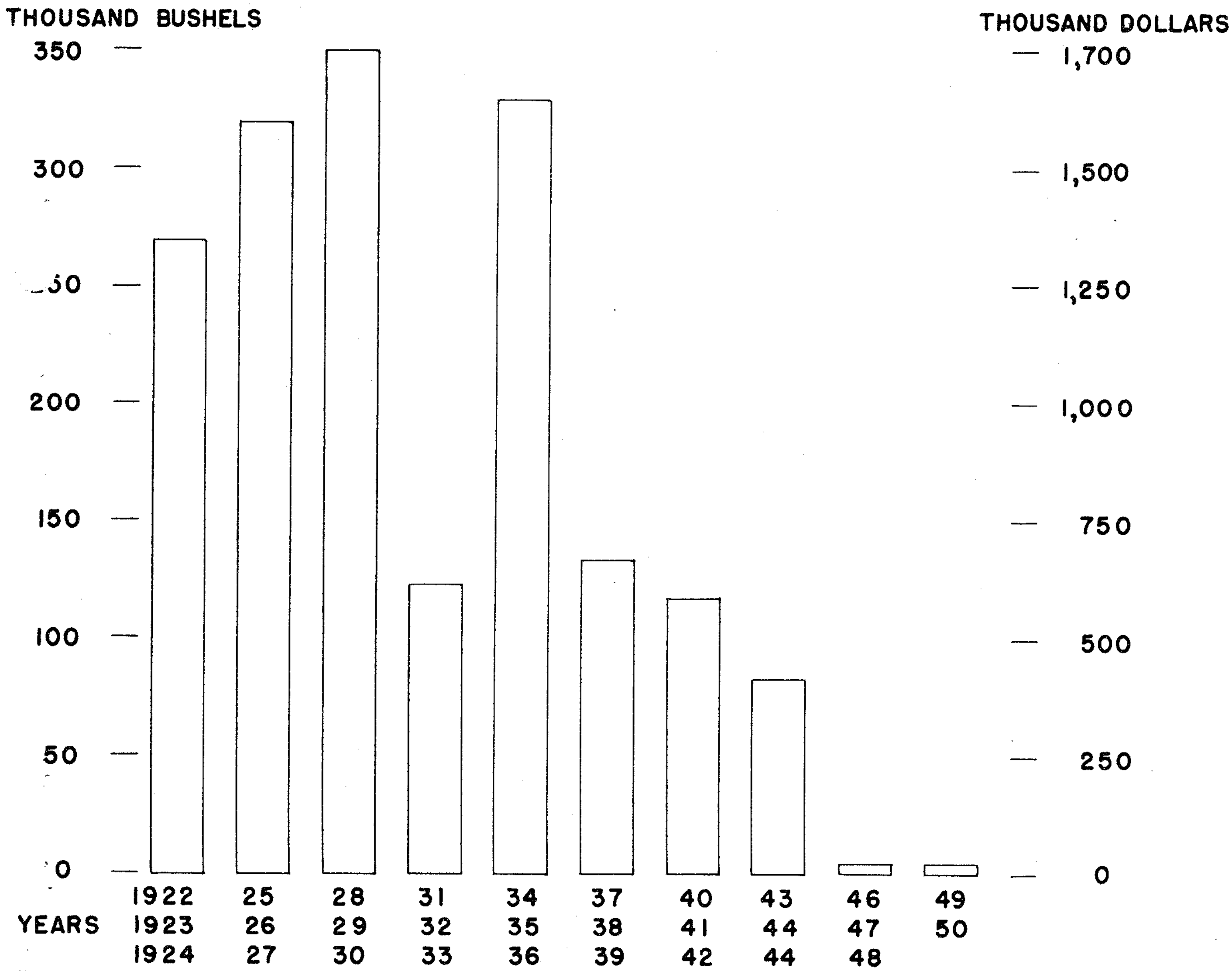

FIG. 3 MARKET OYSTER PRODUCTION IN GREAT SOUTH BAY (PLOTTED AS 3 YR. AVERAGES)
FROM DATA COMPILED BY N.Y.S. CONSERVATION DEPT., BUREAU OF MARINE FISHERIES.

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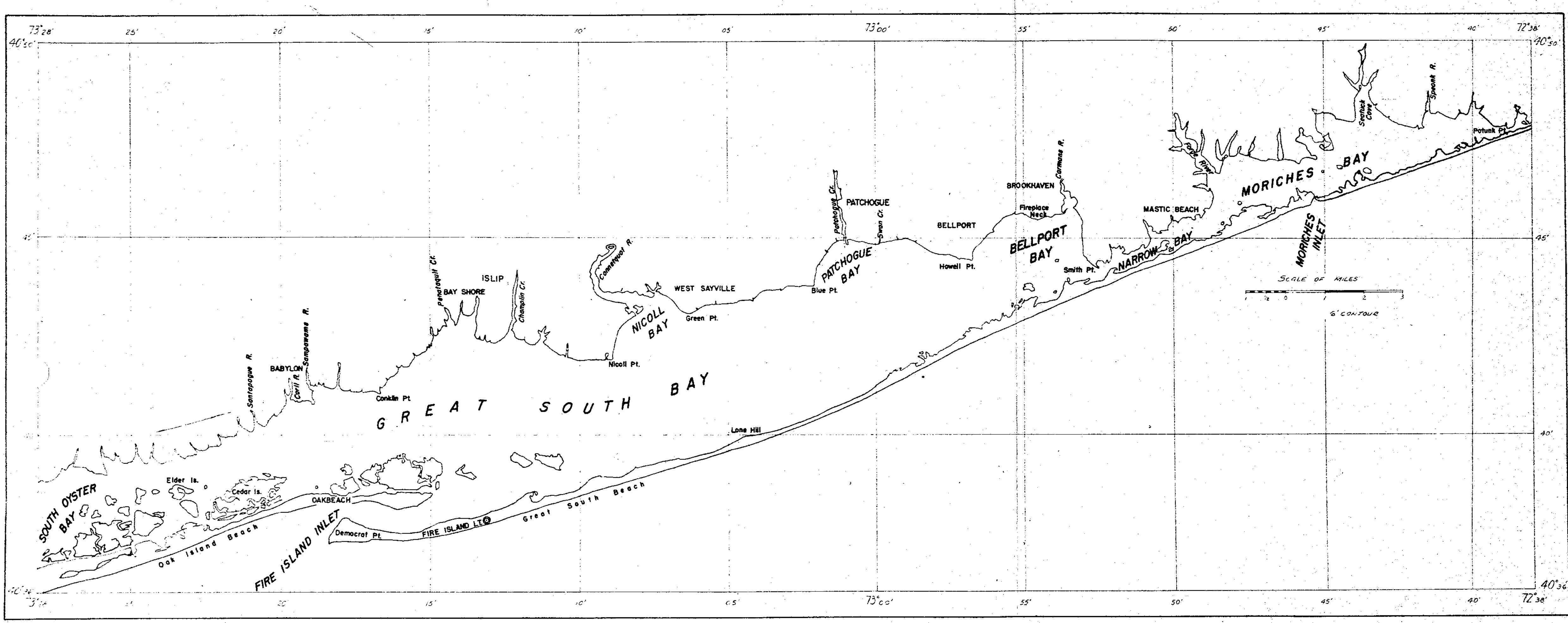

FIG. 4 ORIENTATION CHART OF GREAT SOUTH BAY AND ENVIRONS

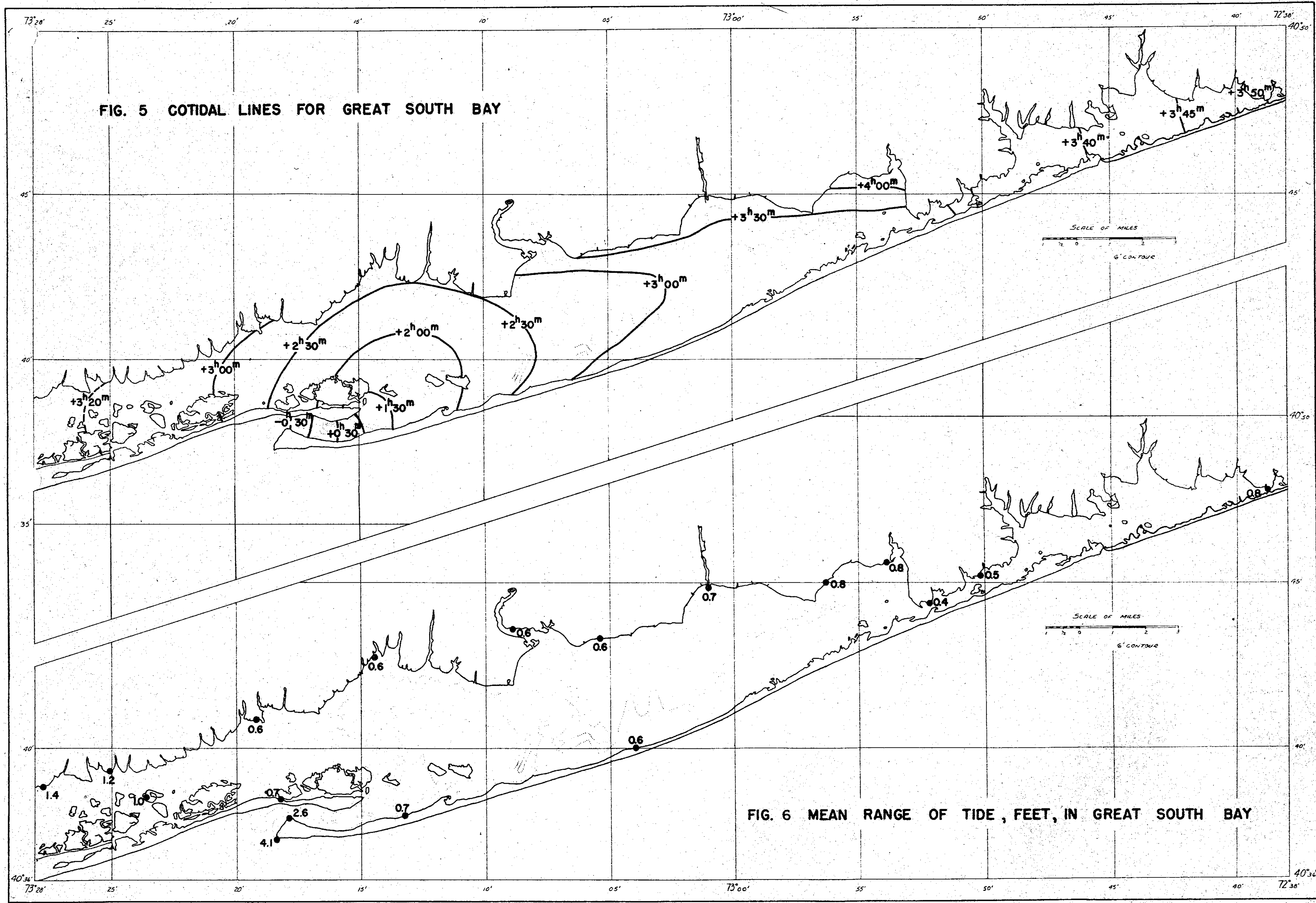

FIG. 5 COTIDAL LINES FOR GREAT SOUTH BAY

FIG. 6 MEAN RANGE OF TIDE, FEET, IN GREAT SOUTH BAY

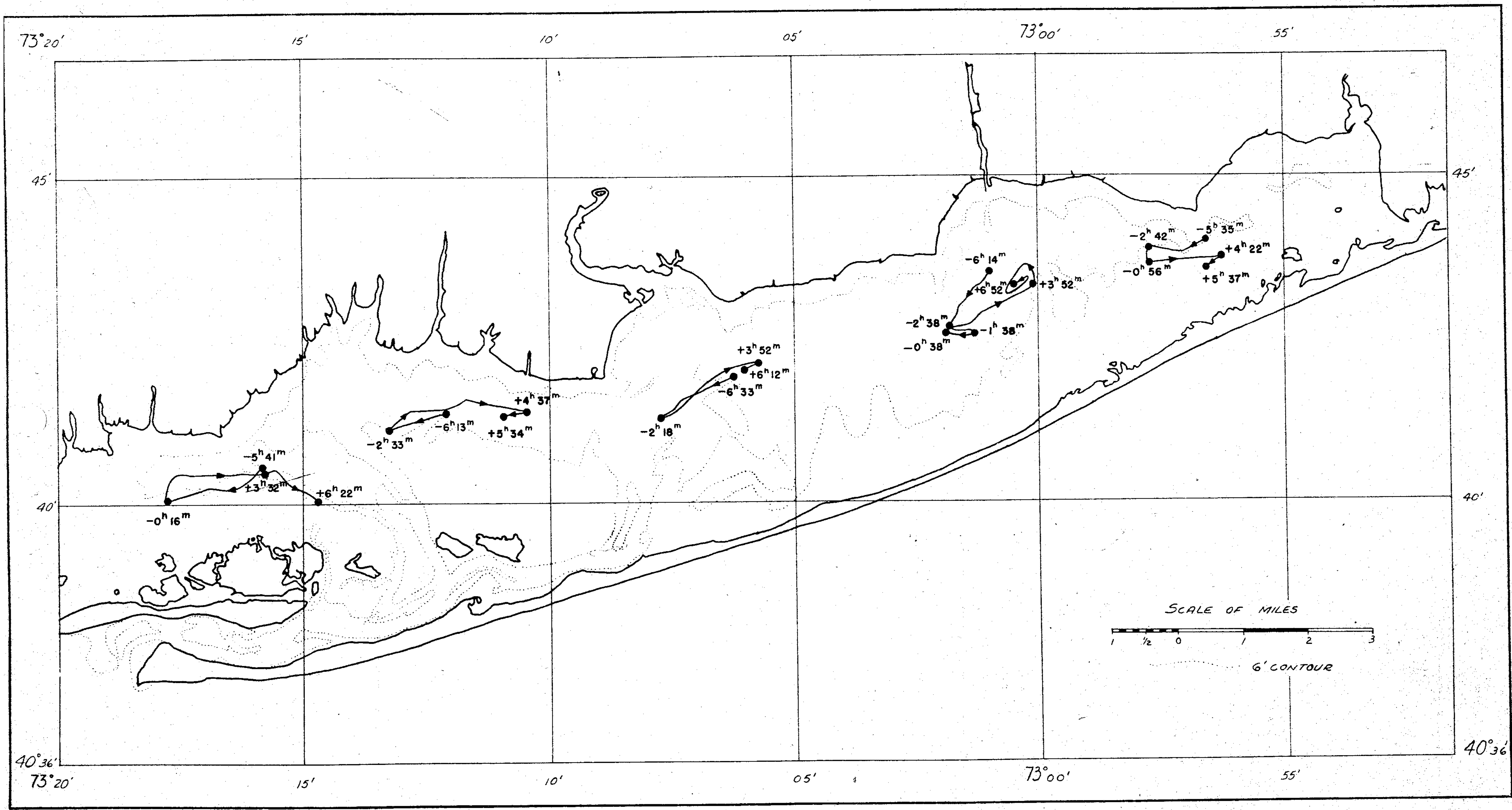

FIG. 7 TIDAL CURRENT MEASUREMENTS WITH DYE MARKER ON 4 AUGUST 1950
TIME REFERENCED TO PREDICTED TIME OF HIGH WATER AT SANDY HOOK. WIND – LIGHT S.W.

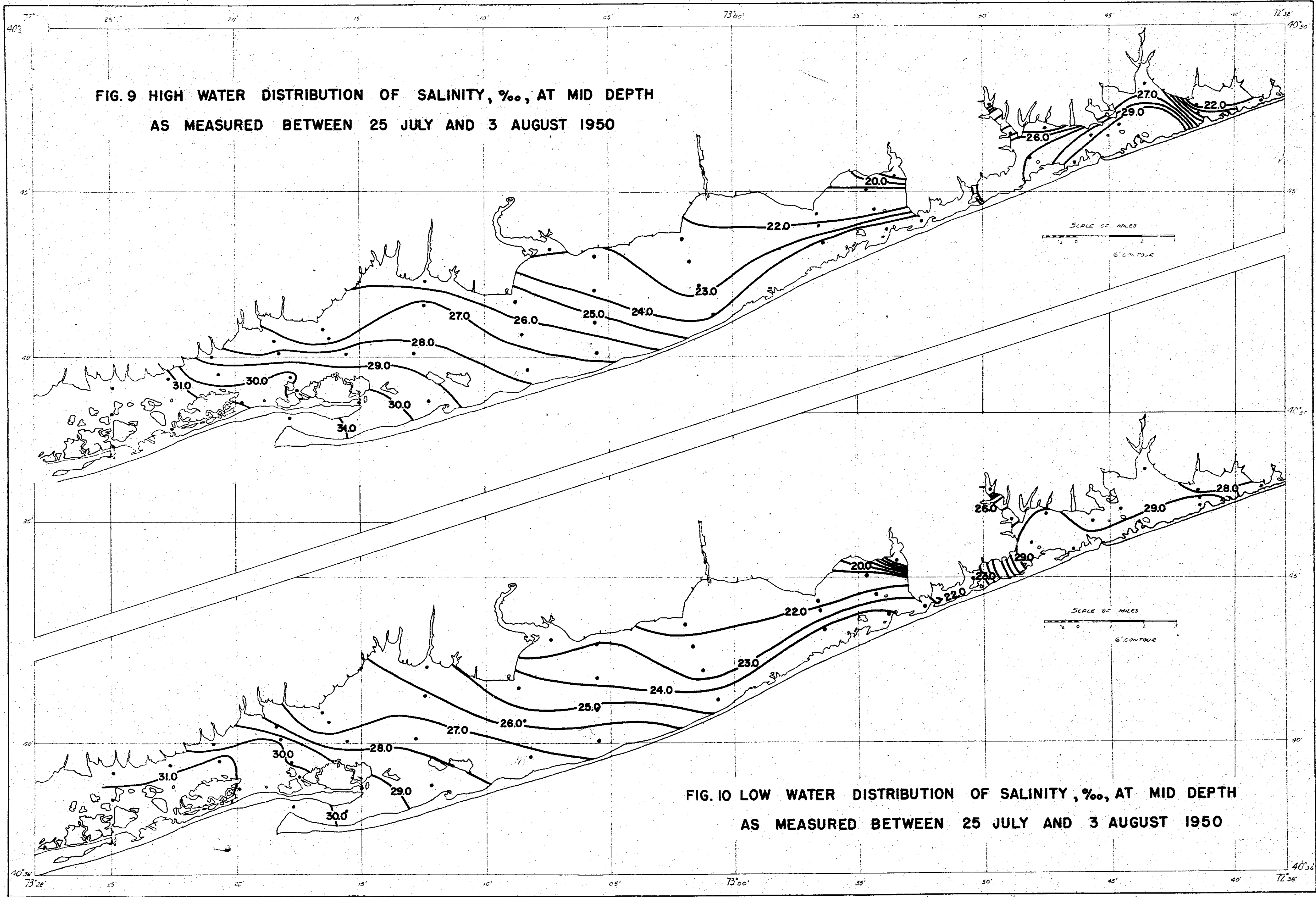

FIG. 9 HIGH WATER DISTRIBUTION OF SALINITY, ‰, AT MID DEPTH AS MEASURED BETWEEN 25 JULY AND 3 AUGUST 1950

FIG. 10 LOW WATER DISTRIBUTION OF SALINITY, ‰, AT MID DEPTH AS MEASURED BETWEEN 25 JULY AND 3 AUGUST 1950

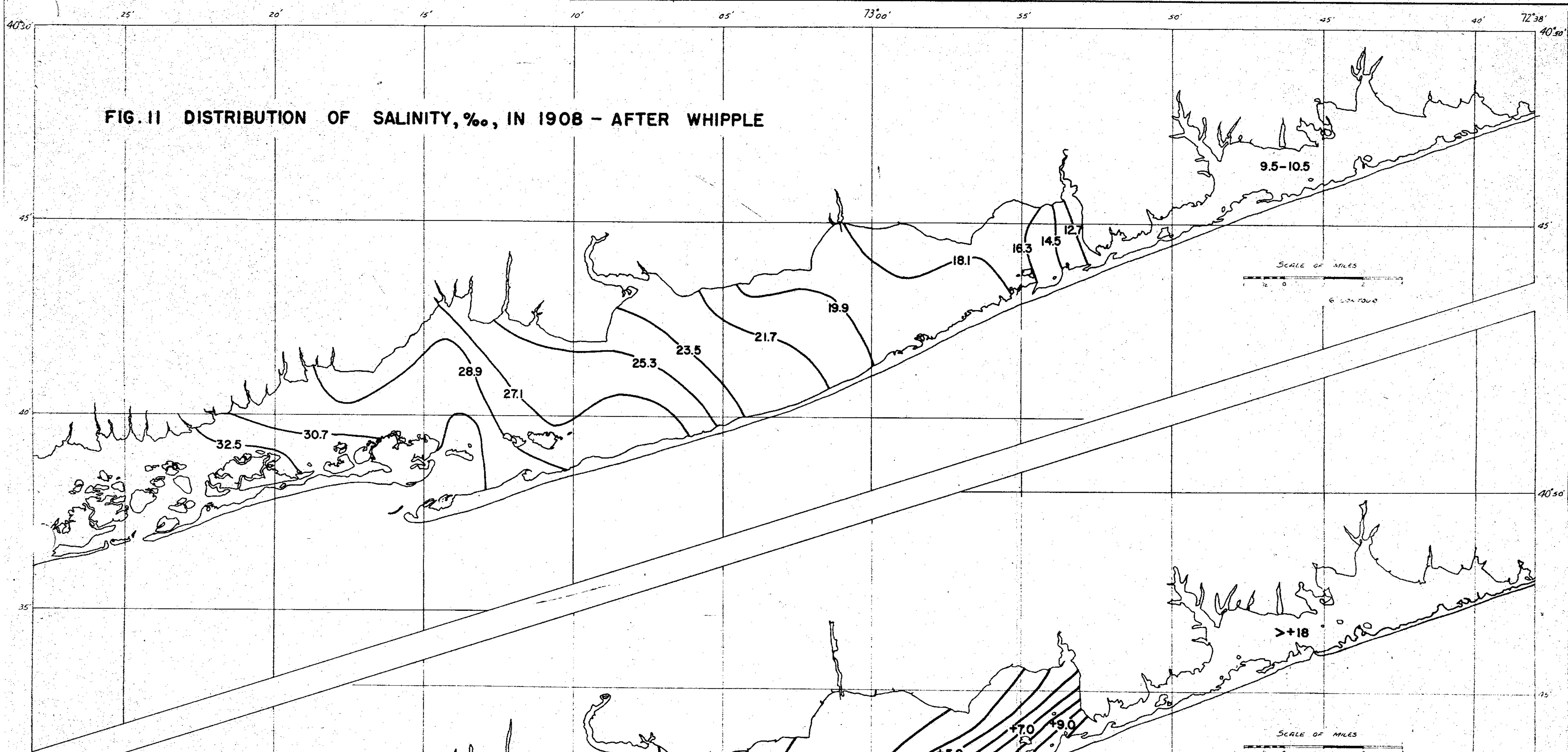

FIG. 11 DISTRIBUTION OF SALINITY, ‰, IN 1908 – AFTER WHIPPLE

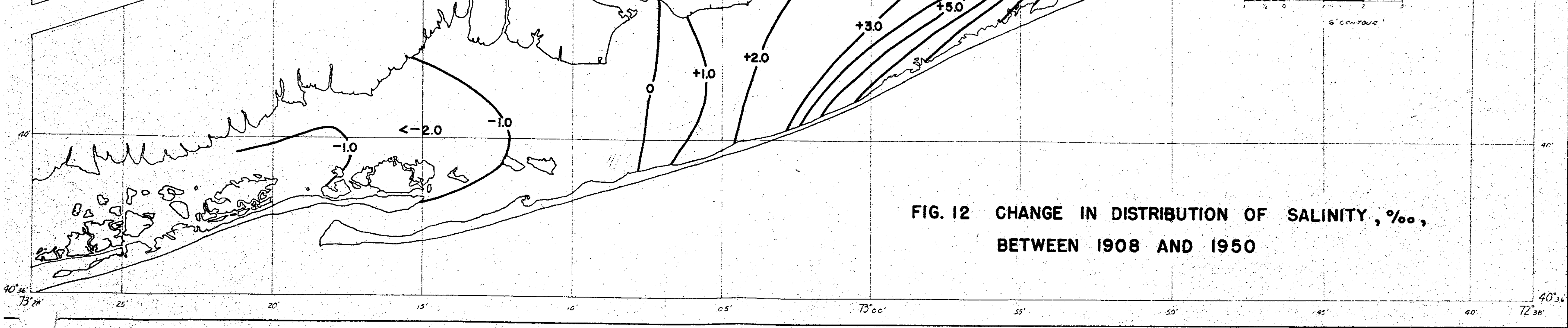

FIG. 12 CHANGE IN DISTRIBUTION OF SALINITY, ‰, BETWEEN 1908 AND 1950

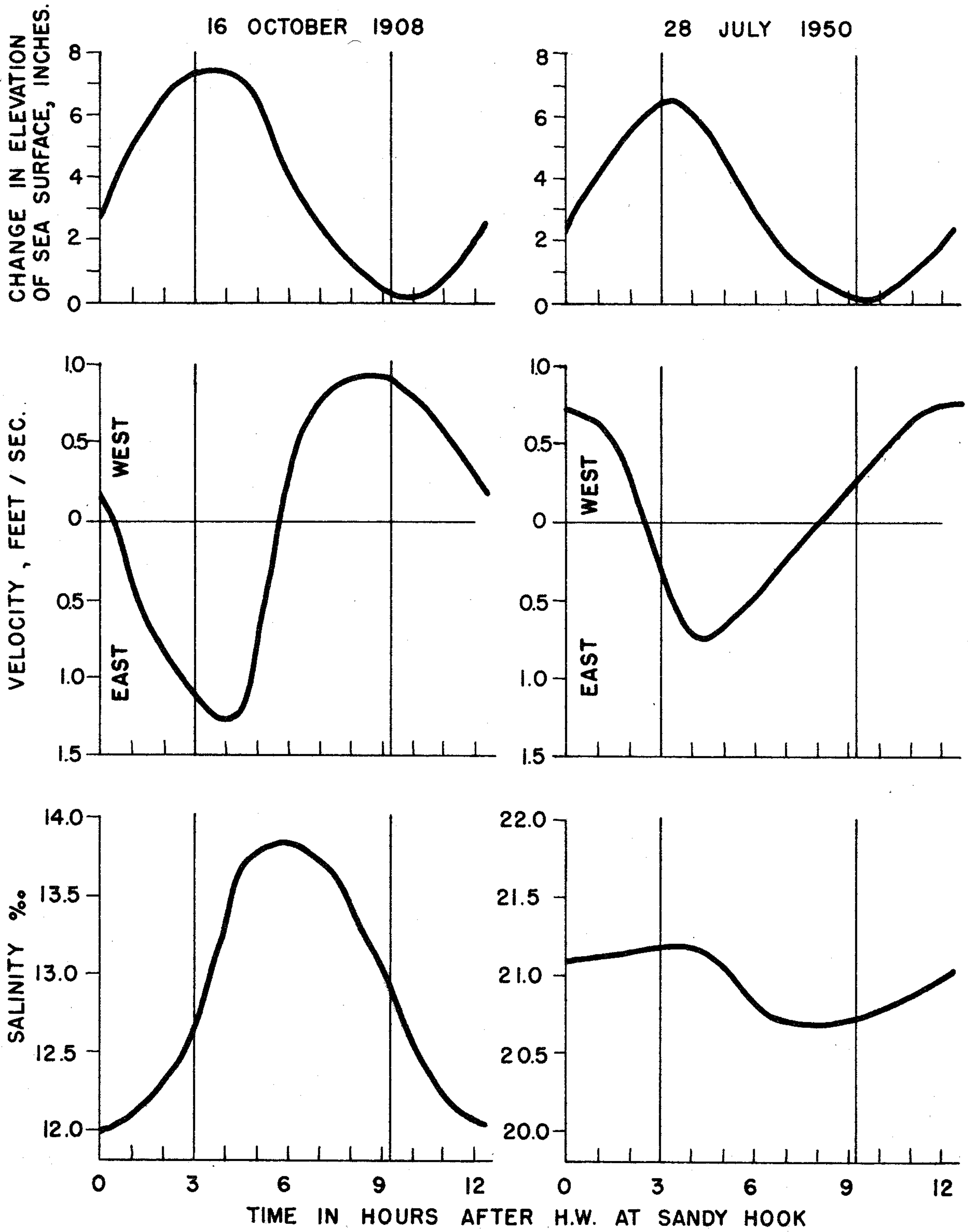

FIG. 13 DIAGRAM SHOWING CHANGE IN ELEVATION OF SEA SURFACE, VELOCITY OF TIDAL CURRENT AND SALINITY OF WATER AT SMITH POINT ON 16 OCT. 1908 AND 28 JUL. 1950

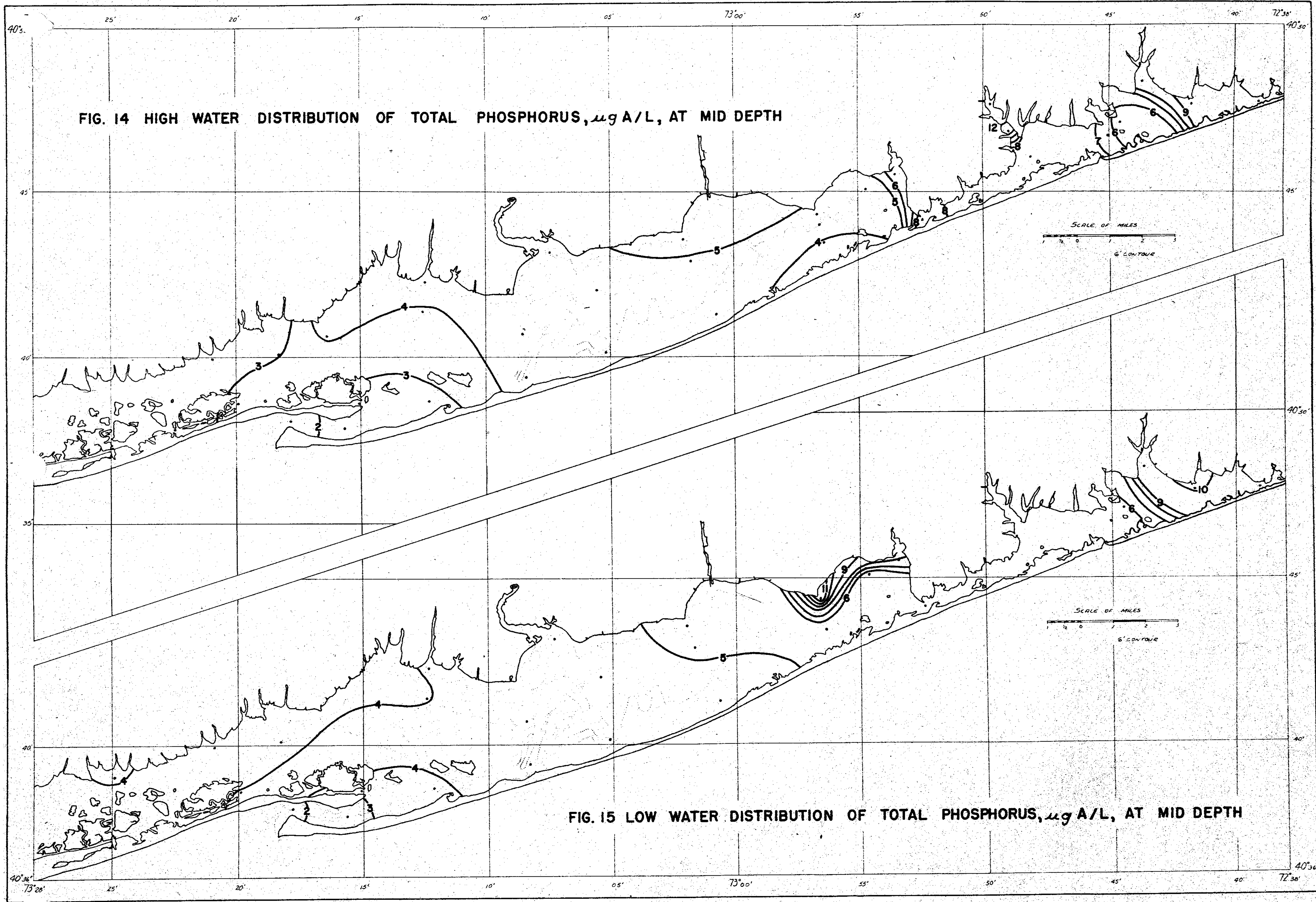

FIG. 14 HIGH WATER DISTRIBUTION OF TOTAL PHOSPHORUS, μg A/L, AT MID DEPTH

FIG. 15 LOW WATER DISTRIBUTION OF TOTAL PHOSPHORUS, μg A/L, AT MID DEPTH

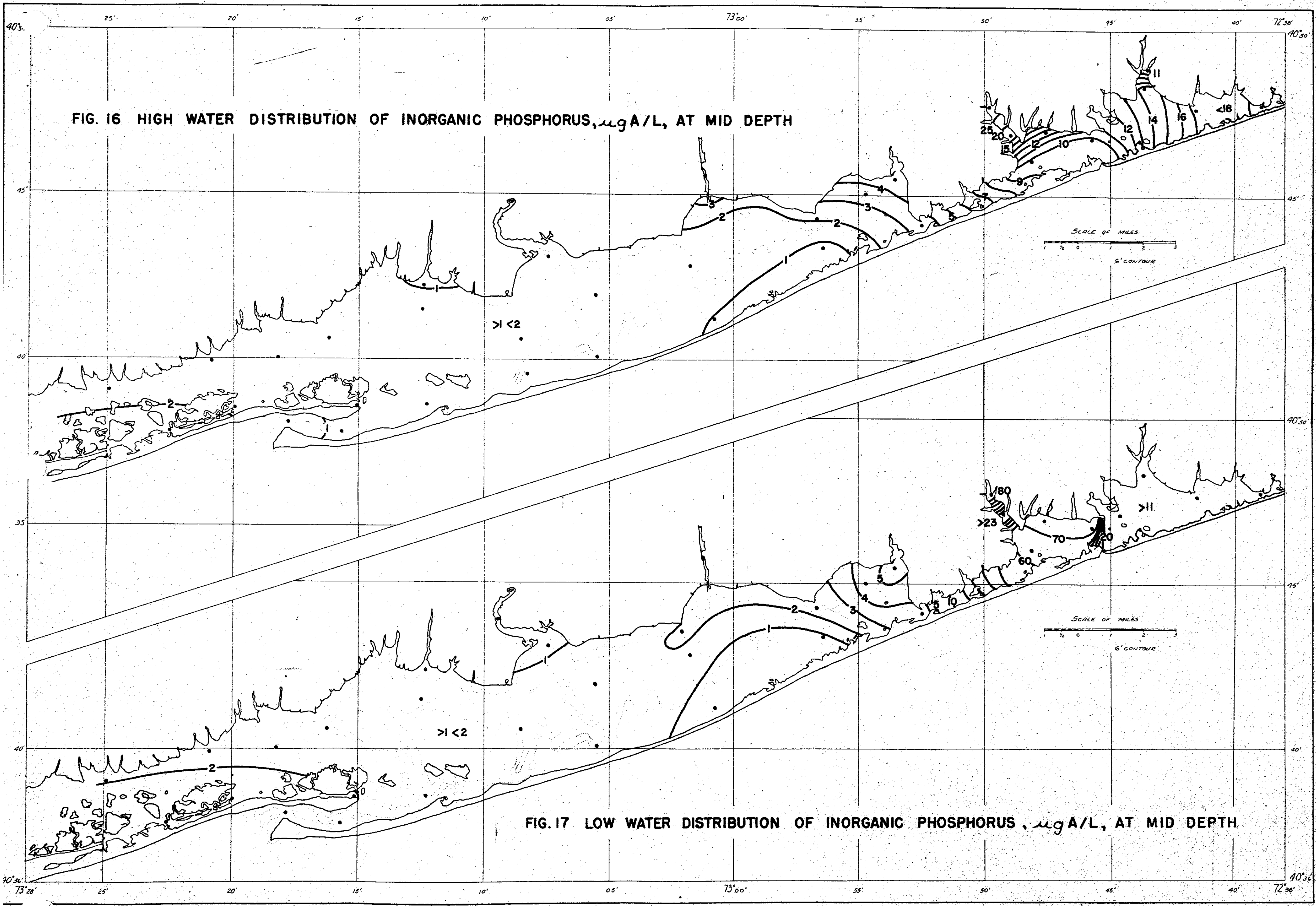

FIG. 16 HIGH WATER DISTRIBUTION OF INORGANIC PHOSPHORUS, μg A/L, AT MID DEPTH

FIG. 17 LOW WATER DISTRIBUTION OF INORGANIC PHOSPHORUS, μg A/L, AT MID DEPTH

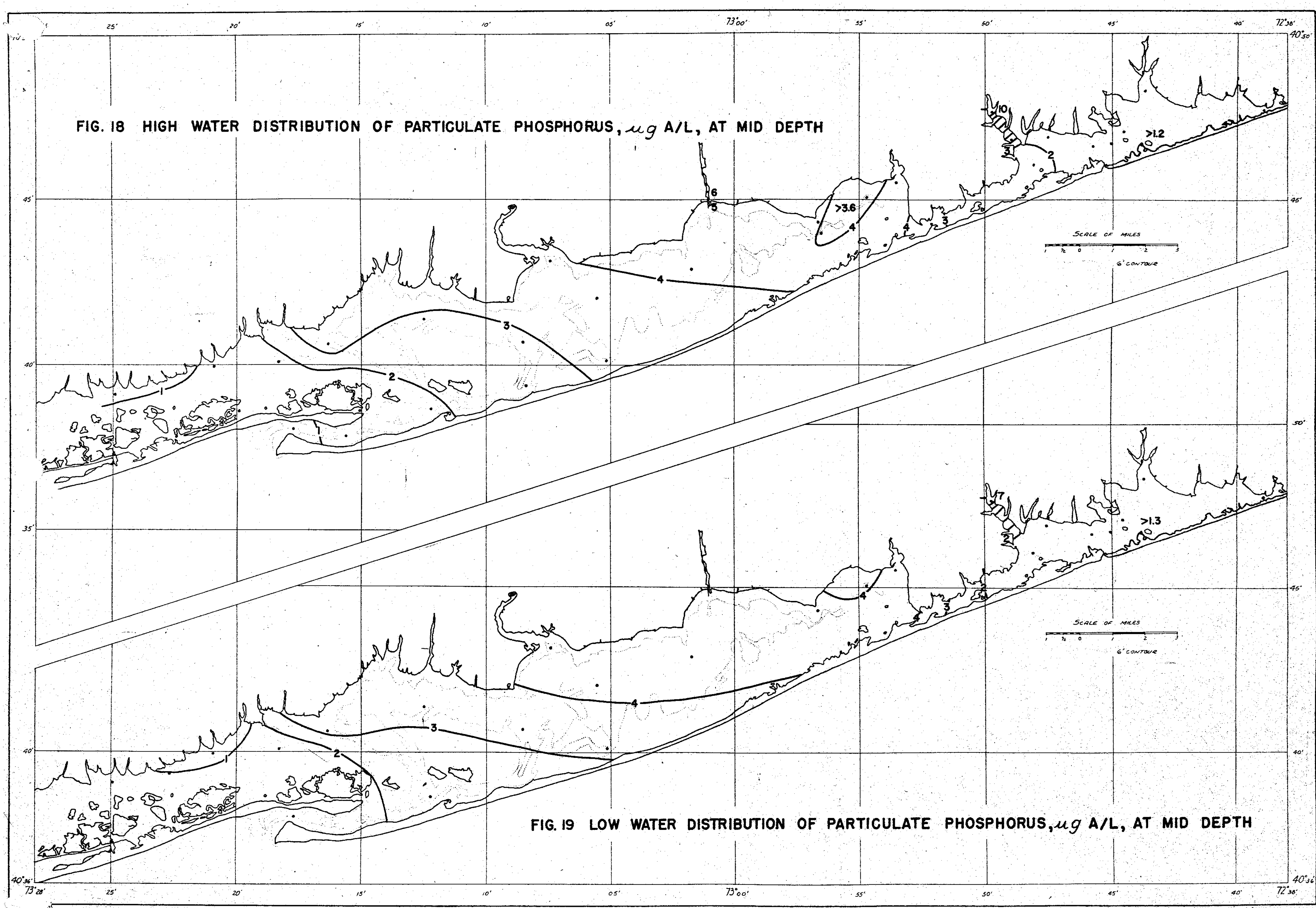

FIG. 18 HIGH WATER DISTRIBUTION OF PARTICULATE PHOSPHORUS, μg A/L, AT MID DEPTH

FIG. 19 LOW WATER DISTRIBUTION OF PARTICULATE PHOSPHORUS, μg A/L, AT MID DEPTH

FIG. 20 AVERAGE DISTRIBUTION OF BOUND PHOSPHORUS, µgA/L, AT MID DEPTH

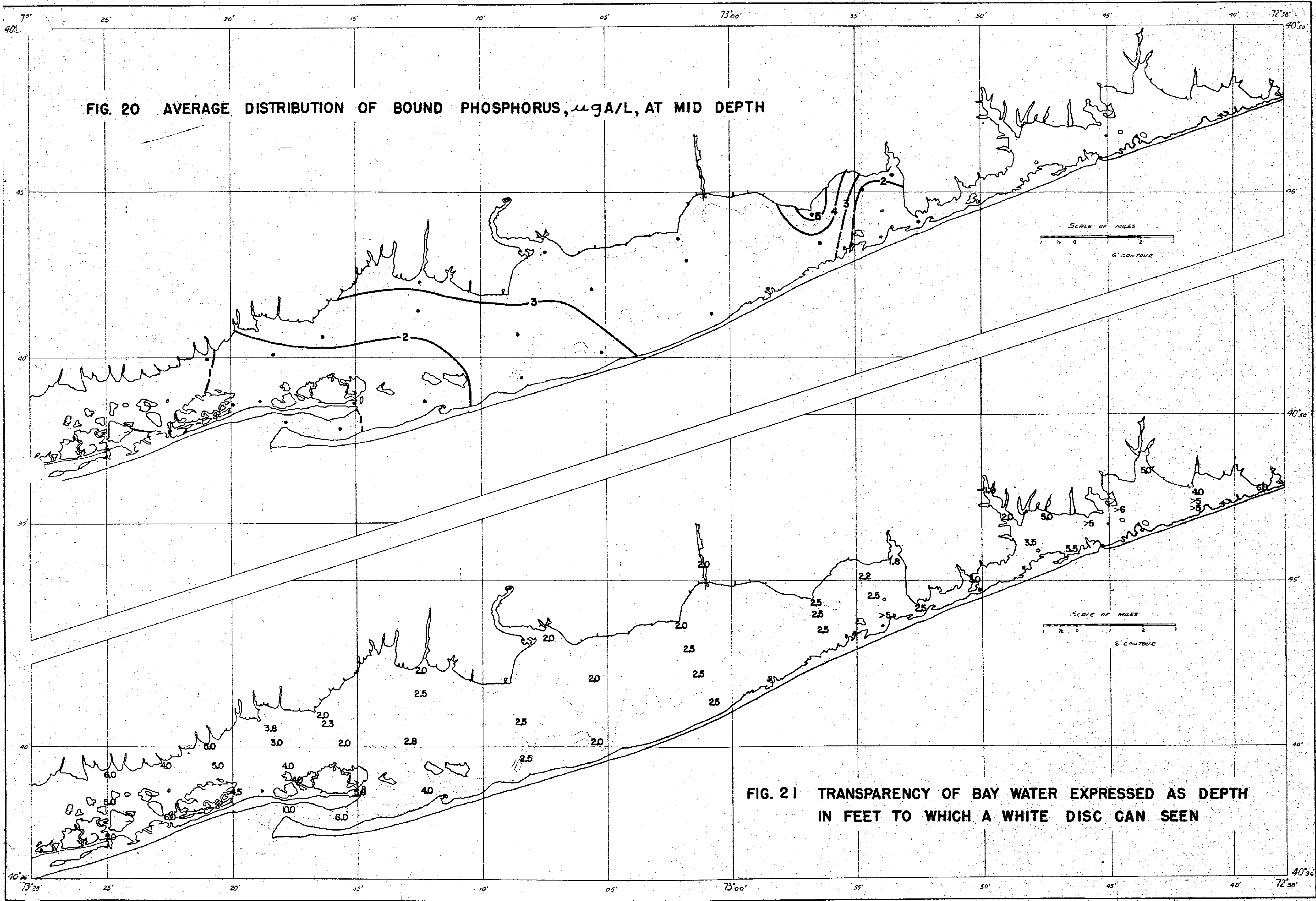

FIG. 21 TRANSPARENCY OF BAY WATER EXPRESSED AS DEPTH IN FEET TO WHICH A WHITE DISC CAN SEEN

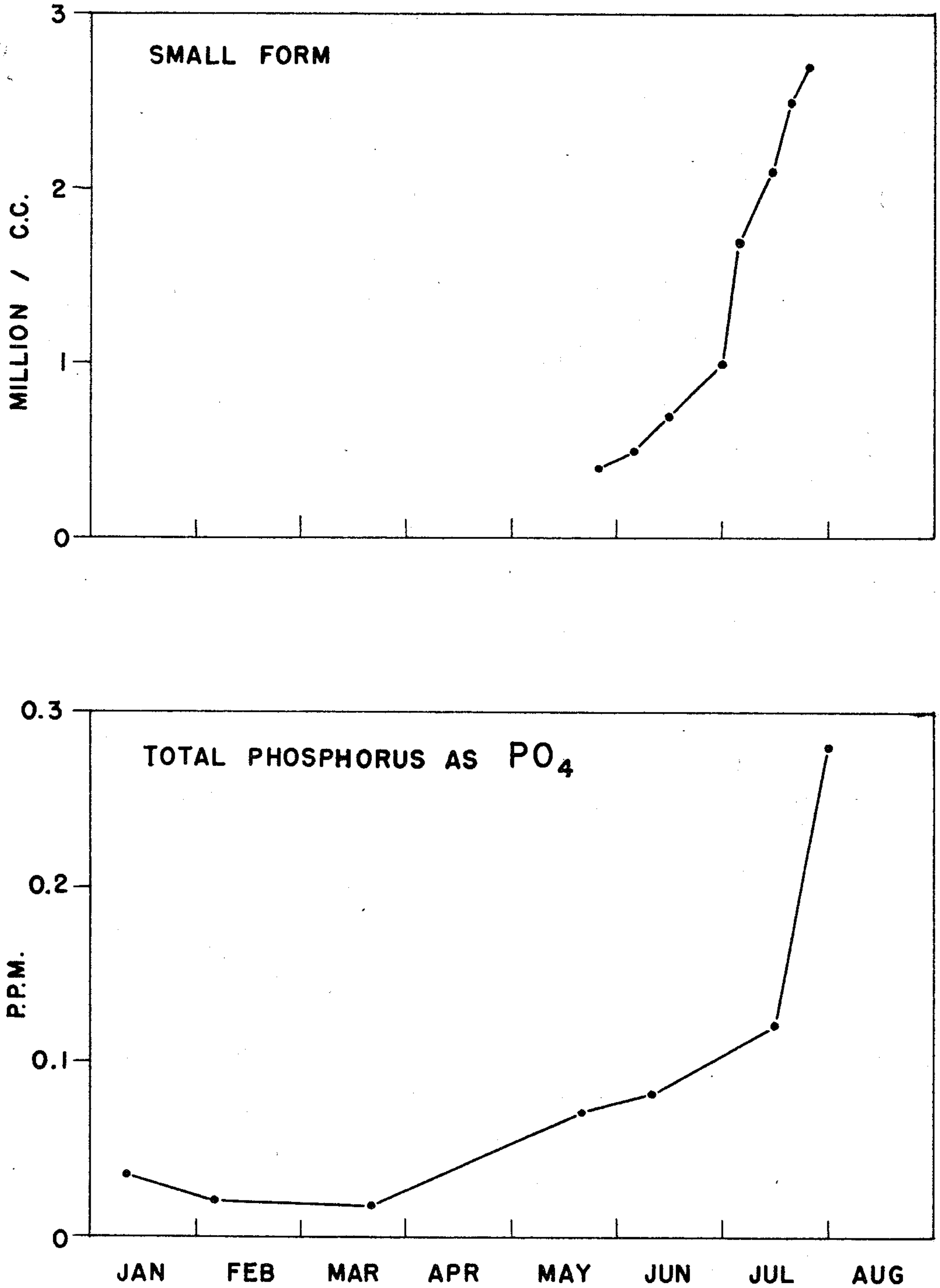

FIG. 22 MONTHLY CONCENTRATION OF SMALL FORM AND TOTAL PHOSPHORUS IN BAY WATER OFF WEST SAYVILLE IN 1950

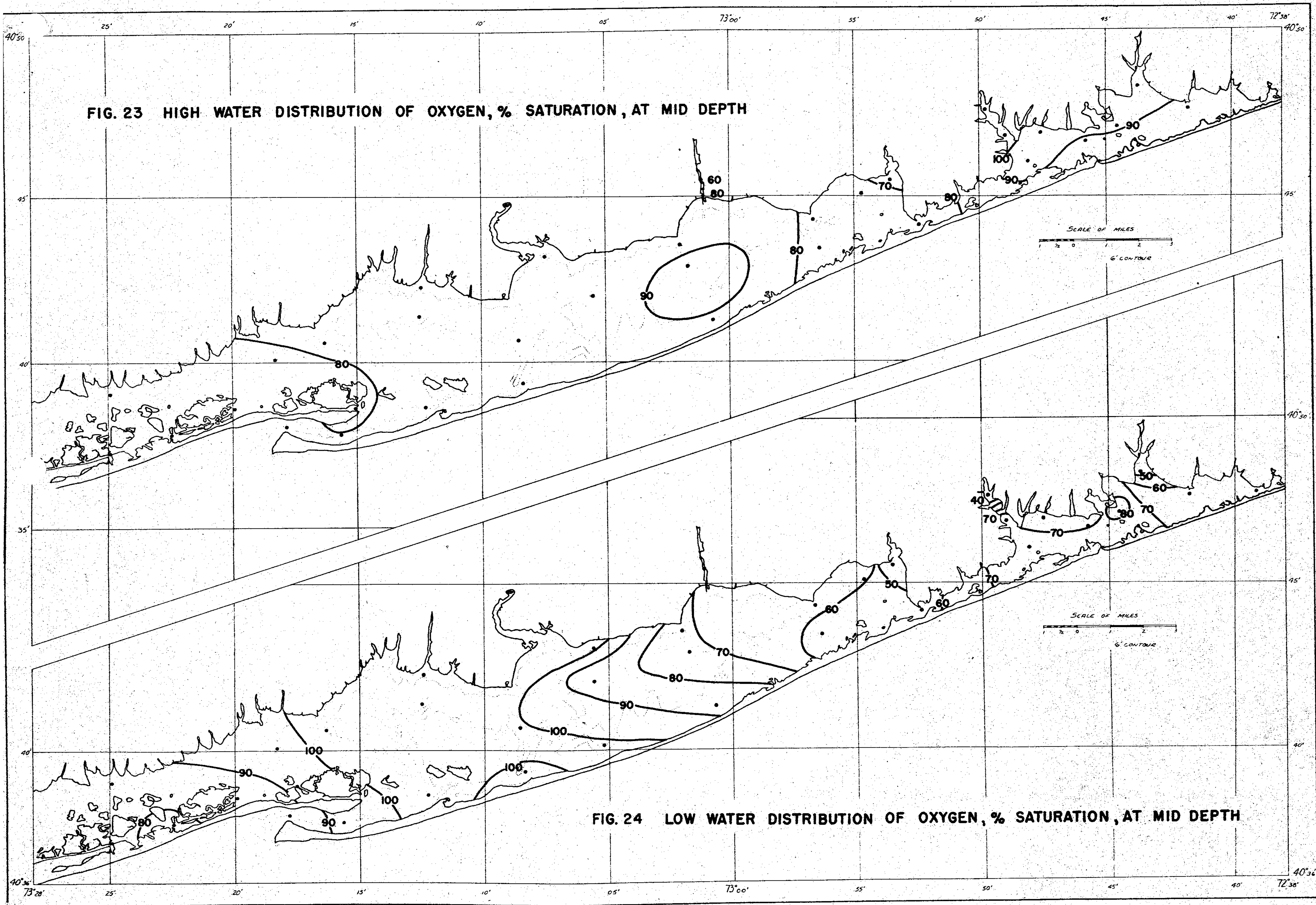

FIG. 23 HIGH WATER DISTRIBUTION OF OXYGEN, % SATURATION, AT MID DEPTH

FIG. 24 LOW WATER DISTRIBUTION OF OXYGEN, % SATURATION, AT MID DEPTH

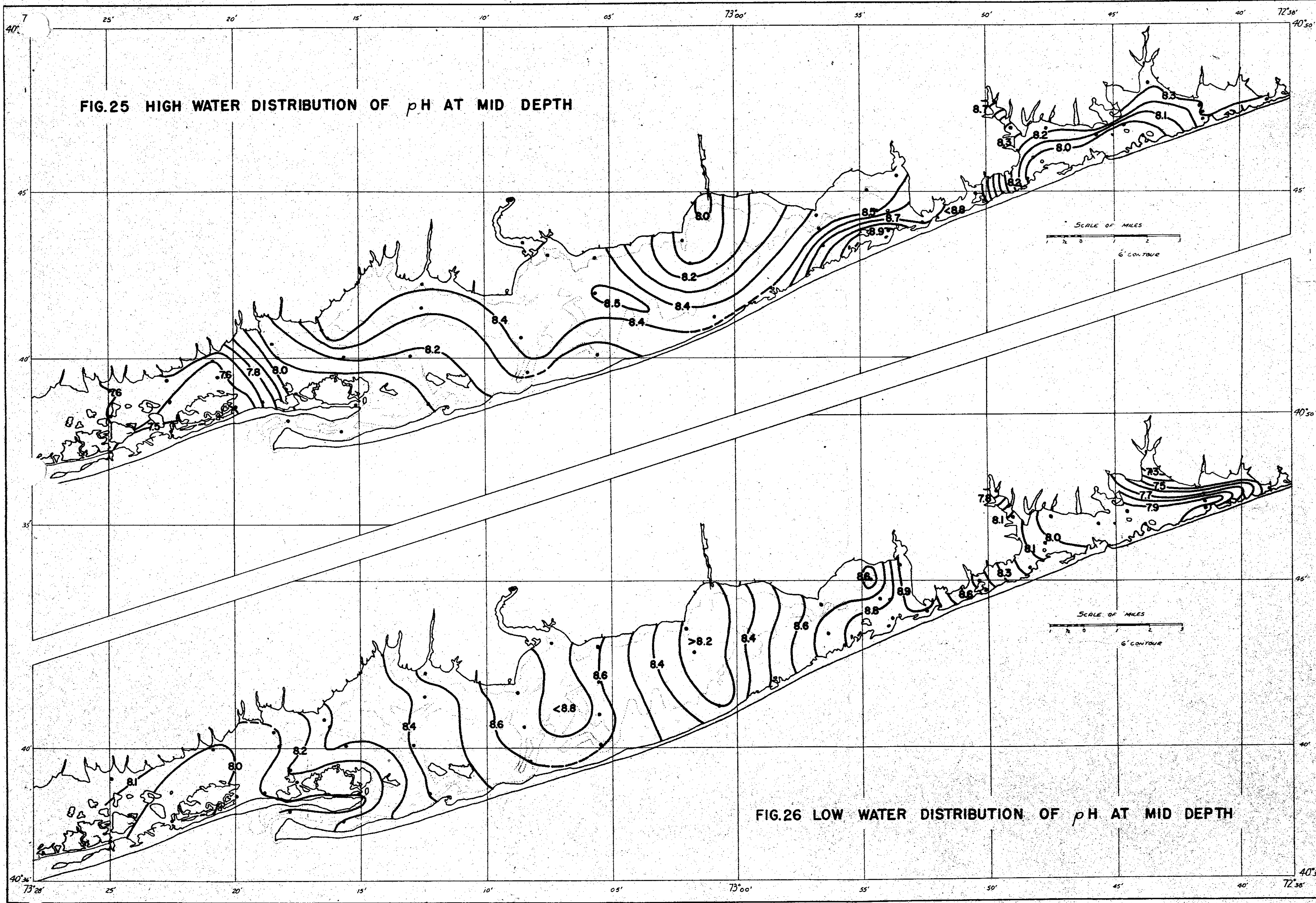

FIG. 25 HIGH WATER DISTRIBUTION OF pH AT MID DEPTH

FIG. 26 LOW WATER DISTRIBUTION OF pH AT MID DEPTH

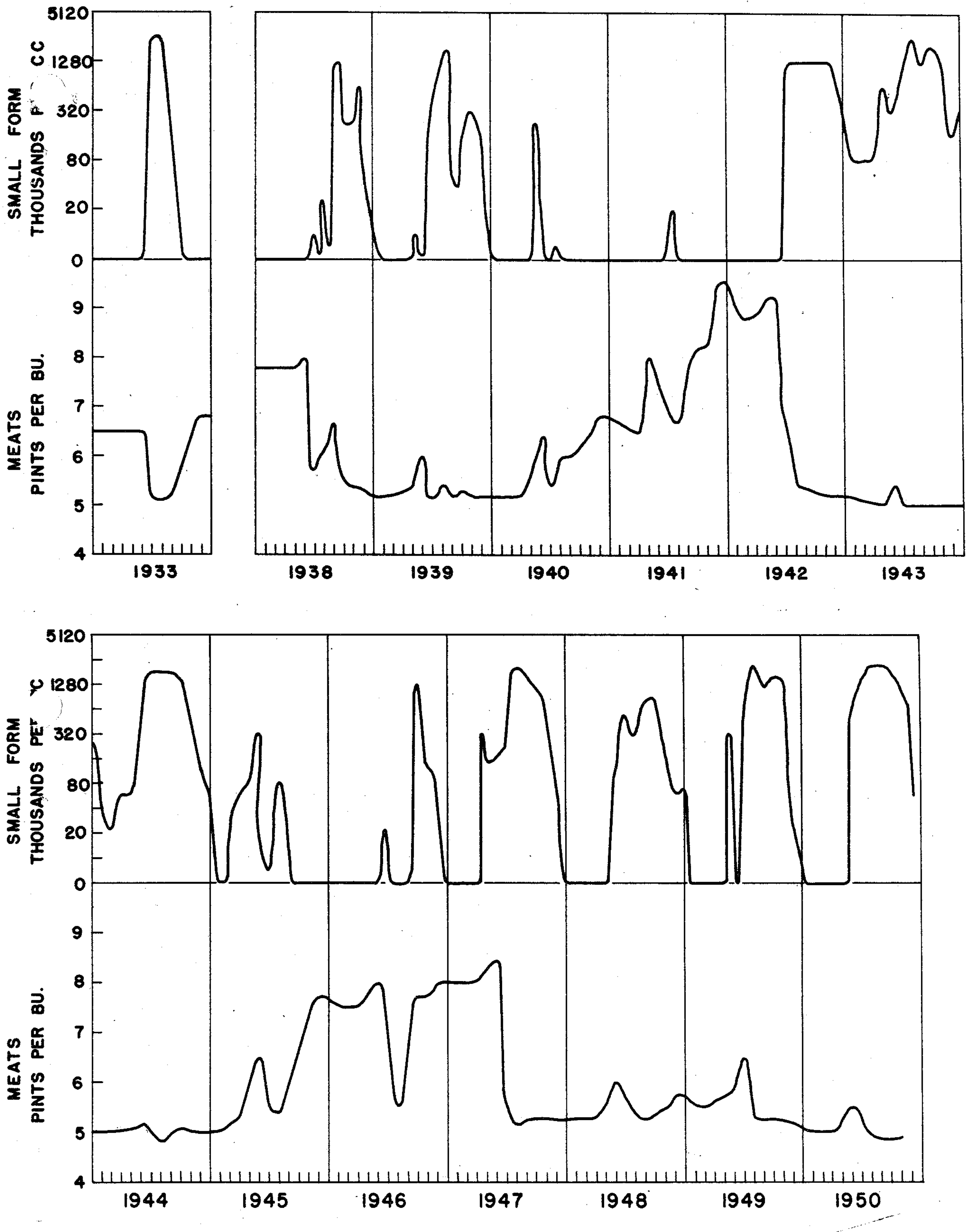

FIG.27 MONTHLY CONCENTRATION OF SMALL FORM OFF WEST SAYVILLE AND VOLUME OF MEATS PER BUSHEL OF OYSTERS FOR THE YEARS 1933 TO 1950